  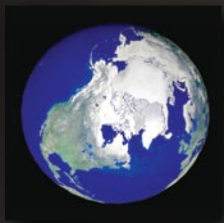  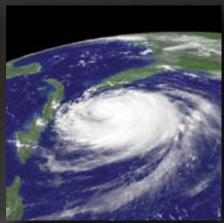 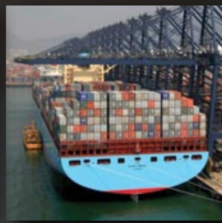

CHARTING THE COURSE FOR OCEAN SCIENCE IN THE UNITED STATES FOR THE NEXT DECADE

AN OCEAN RESEARCH PRIORITIES PLAN AND IMPLEMENTATION STRATEGY

NSTC JOINT SUBCOMMITTEE ON OCEAN SCIENCE AND TECHNOLOGY

JANUARY 26, 2007

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AN OCEAN RESEARCH PRIORITIES PLAN AND IMPLEMENTATION STRATEGY

NSTC JOINT SUBCOMMITTEE ON OCEAN SCIENCE AND TECHNOLOGY

JANUARY 26, 2007

Council on Environmental Quality
Office of Science and Technology Policy
Executive Office of the President
January 26, 2007

Dear Partners and Friends in our Ocean and Coastal Community,

We are pleased to transmit to you this report, ***Charting the Course for Ocean Science for the United States for the Next Decade: An Ocean Research Priorities Plan and Implementation Strategy.*** This document presents national research priorities that focus on the most compelling issues in key areas of interaction between society and the ocean.

In 2000, Congress tasked the U.S. Commission on Ocean Policy to investigate and provide recommendations for a "coordinated and comprehensive national ocean policy." After extensive hearings, written input, and public comment, the Ocean Commission published *An Ocean Blueprint for the 21st Century* with more than 200 recommendations. The Bush Administration responded to these recommendations with the U.S. Ocean Action Plan, a broad plan that fundamentally restructured ocean governance, research, and management to "engender responsible use and stewardship of ocean and coastal resources for the benefit of all Americans."

The Ocean Action Plan called for the development of a national ocean research priorities plan and implementation strategy to provide a framework for research investments in ocean science for the coming decade. Through a collaborative process involving stakeholders from the relevant federal agencies as well as state and local governments, academia, industry, and non-governmental organizations, the National Science and Technology Council's Joint Subcommittee on Science and Technology, the interagency group tasked with the development of the plan, also reports via the Interagency Committee on Ocean Science and Resource Management Integration to the Cabinet level Committee on Ocean Policy.

This document draws from the contributions of numerous scientific and technical experts, resource managers, and concerned citizens who participated in public workshops, regional conferences, and responded to draft documents. Ultimately, the National Academy of Sciences–National Research Council Ocean Studies Board reviewed the plan.

As pointed out by the U.S. Commission on Ocean Policy, "America is a nation intrinsically connected to and immensely reliant on the ocean." Given the importance of our waterways - including the open ocean, coasts, coastal watersheds, and Great Lakes - to societal well-being, quality of life, and the economy, our research priorities will harness the greatest opportunities to advance our understanding of critical processes and interactions and facilitate responsible use of the ocean environment, and help ensure the health and sustainability of our Nation's ocean ecosystem for years to come.

Sincerely,

James L. Connaughton
Chair, Committee on Ocean Policy
Chair, Council on Environmental Quality

John H. Marburger, III
Director
Office of Science and Technology Policy

In This Report

Numbered superscripts indicate endnotes.

On the Cover

From left to right

1 Photo courtesy of the *Ocean Blueprint for the 21st Century.* This image appeared in *MMS Ocean Science*, Volume 3, Issue 5 and is reprinted with permission of the U.S. Department of the Interior's Minerals Management Service

2 From Backer, L.C. and D.J. McGillicuddy. 2006. *Oceanography* 19(2), Figure 8 by OhioView/T. Bridgeman

3 Lake Erie bloom. Arctic shot—NASA JPL, University of Alaska - Fairbanks

4 Department of Interior

5 Photo courtesy of NOAA. This image appeared in *MMS Ocean Science*, Volume 3, Issue 5 and is reprinted with permission of the U.S. Department of the Interior's Minerals Management Service.

6 Emma Maersk

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Executive Summary

Proper stewardship of the ocean is critical to the long-term vitality of the United States. The ocean, consisting of the open ocean, coasts, coastal watersheds, and Great Lakes, provides food and recreation, contributes to the nation's economic engine, is an element of national security, and is a major influence on the global climate system. Despite its vast extent, the ocean is finite and cannot indefinitely absorb all the stresses being placed on it; thus, the United States must commit to protecting the ocean through responsible stewardship and sensible management. Understanding society's impact on the ocean and the ocean's impact on society forms the basis for ensuring a clean, healthy, and stable ocean environment that can be responsibly used and enjoyed for generations to come. The goal of this document is to provide the guidance to build the scientific foundation to improve society's stewardship and use of, and interaction with, the ocean.

Three central elements of science and technology will provide the United States with the knowledge and means to redefine its relationship with the ocean for the better. The *capability to forecast key ocean and ocean-influenced processes and phenomena* will change how society takes action in the future, much like weather forecasts do today. Developing the understanding and capability to forecast key processes related to hurricane and severe-storm formation, ocean currents, fish stocks, and human-health hazards, to name a few, will have significant economic, societal, and environmental benefits. Providing the *scientific support for ecosystem-based management* will allow resources to be managed in ways that account for the complex interactions between those resources and other parts of the marine environment, including humans. *Deploying an ocean-observing system* that can accurately describe the state of the ocean will revolutionize the access to and view of the ocean and increase the pace, efficiency, and scope of ocean research. In turn, this observing capability will enable ocean forecasting and ecosystem-based management.

The focus on ocean forecasting, scientific support for ecosystem-based management, and ocean-observing capabilities was born out of a comprehensive community effort to define ocean research priorities for the United States for the next decade. Aspects of these three central elements are evident throughout the twenty (20) national ocean research priorities, oriented around the most compelling issues in key areas of interaction between society and the ocean (societal themes). These priorities, each with equal weight, focus on understanding critical ocean processes and interactions, and applying that understanding toward stewardship and responsible use of the ocean.

Theme 1: Stewardship of Natural and Cultural Ocean Resources

Research Priority 1: Understand the status and trends of resource abundance and distribution through more accurate, timely and synoptic assessments

Research Priority 2: Understand interspecies and habitat/species relationships to support forecasting resource stability and sustainability

Research Priority 3: Understand human-use patterns that may influence resource stability and sustainability

Research Priority 4: Apply advanced understanding and technologies to enhance the benefits of various natural resources from the open ocean, coasts, and Great Lakes

Theme 2: Increasing Resilience to Natural Hazards

Research Priority 5: Understand how hazard events initiate and evolve and apply that understanding to improve forecasts of future hazard events

Research Priority 6: Understand the response of coastal and marine systems to natural hazards and apply that understanding to assessments of future vulnerability to natural hazards

Research Priority 7: Apply understanding to develop multi-hazard risk assessments and support development of models, policies, and strategies for hazard mitigation

Theme 3: Enabling Marine Operations

Research Priority 8: Understand the interactions between marine operations and the environment

Research Priority 9: Apply understanding of environmental factors affecting marine operations to characterize and predict conditions in the maritime domain

Research Priority 10: Apply understanding of environmental impacts and marine operations to enhance the marine transportation system

Theme 4: The Ocean's Role in Climate

Research Priority 11: Understand ocean-climate interactions within and across regions

Research Priority 12: Understand the impact of climate variability and change on the biogeochemistry of the ocean and implications for its ecosystems

Research Priority 13: Apply understanding of the ocean to help project future climate changes and their impacts

Theme 5: Improving Ecosystem Health

Research Priority 14: Understand and predict the impact of natural and anthropogenic processes on ecosystems

Research Priority 15: Apply understanding of natural and anthropogenic processes to develop socioeconomic assessments and models to evaluate the impact of multiple human uses on ecosystems

Research Priority 16: Apply understanding of marine ecosystems to develop appropriate indicators and metrics for sustainable use and effective management

Theme 6: Enhancing Human Health

Research Priority 17: Understand sources and processes contributing to ocean-related risks to human health

Research Priority 18: Understand human health risks associated with the ocean and the potential benefits of ocean resources to human health

Research Priority 19: Understand how human use and valuation of ocean resources can be affected by ocean-borne human health threats and how human activities can influence these threats

Research Priority 20: Apply understanding of ocean ecosystems and biodiversity to develop products and biological models to enhance human well-being

Four near-term priorities, reflecting efforts to be pursued over the next two to five years, were developed to initiate rapid progress towards the 20 ocean research priorities.

1 Forecasting the Response of Coastal Ecosystems to Persistent Forcing and Extreme Events

Understanding and forecasting the response of natural and constructed landscapes and ecosystems to extreme weather events, natural disasters, and changing ocean conditions will inform hazard mitigation and response plans, support navigation safety, and assist regional resource managers and public health officials in sustaining ecosystem and public health and promoting hazard resilience.

2 Comparative Analysis of Marine Ecosystem Organization

Marine ecosystem management can be improved by elucidating their underlying dynamics at a variety of scales through development of dynamics models and their application in comparisons of managed ecosystems. This effort will provide a greater basic understanding of ecosystem processes and practical tools for evaluating the effectiveness of local and regional ecosystem-based management efforts.

3 Sensors for Marine Ecosystems

New sensor capabilities are necessary to realize the full potential of *in situ* ocean observing networks and satellite-based observations. These capabilities will enable expanded and more accurate information on the ocean environment to better define management options, understand processes that influence ecosystem productivity, serve as the basis for forecasting ocean-related risks to human health and safety, and shed light on the impact of climate variability and change on the ocean, marine life, and humans.

4 Assessing Meridional Overturning Circulation Variability: Implications for Rapid Climate Change

The meridional overturning circulation (MOC) of the Atlantic Ocean, an element of the global-scale ocean circulation responsible for long-term climate variations, has been identified as a key process related to rapid or even abrupt climate change (i.e., changes over a few years to a few decades). Improved understanding of this major component of ocean circulation and the ability to monitor, detect, and analyze changes in it could improve society's response to significant changes in climate.

Common among the societal themes is the need to develop the tools necessary to pursue research and to effectively translate the results of that research in ways that are useful to resource managers, policy-makers, and the general public. Society's ability to knowledgeably address key ocean-related societal issues depends on technological and intellectual innovation, incorporating many infrastructure assets, including ocean-observing and modeling capabilities. A healthy relationship between society and the ocean depends on having the scientific foundation to develop and implement new strategies to educate and instill a sense of stewardship in the public and translate research results into effective decision-making tools.

This document's final section details an implementation strategy that will ensure the ocean research priorities are successfully addressed. The implementation strategy describes characteristics of implementation, roles of various sectors, mechanisms for collaboration, the need for an infrastructure assessment, mechanisms for research translation, strategies for assessment and evaluation, and mechanisms for budget and plan updates. It does not stipulate specific federal-agency actions or budgets, provide timelines for activities, or mandate how other sectors should respond to the research priorities independent of federal collaboration—activities that are best defined in specific project plans. Carrying out this implementation strategy will require a national and international effort involving many sectors of the ocean community, from state, local, and tribal governance to academic institutions to nongovernmental organizations.

Vision for National Ocean Research Priorities

We envision a future in which our understanding of the world ocean, national coasts, coastal watersheds, and Great Lakes protects lives, enriches livelihoods, and enhances quality of life. At the same time, the research we undertake will help ensure the health and sustainability of our ocean ecosystem for years to come.

As expressed by the U.S. Commission on Ocean Policy (USCOP) and similar community efforts, increased scientific knowledge of the ocean will strengthen decision-making at all levels, enhance economic development, support sustainable resource use, and conserve biological diversity and natural beauty.

As the linchpin in this vision of the future, ocean research, bolstered by cutting-edge technology, will give us the ability to understand the past, observe the present, and predict the future. As an educated and informed nation, our knowledge will give us the tools to know well what the consequences and outcomes of our actions will be in the complex ocean ecosystems of which we are a part.

Introduction

The basic necessities for protecting lives, enhancing livelihoods, and improving quality of life depends, in no small measure, on functioning and healthy ocean ecosystems, the availability of ocean resources, and on a safe and secure maritime domain and associated marine-based economic sectors. The ocean[1] provides food, recreation, and other forms of enrichment, but at the same time, presents risks that, if not understood and respected, pose serious threats to lives and livelihoods. Informed management of the ocean environment will prevent or minimize the risks of illness and disease; bolster the resilience of coastal communities and regions to hazards that arise from the marine environment; enhance the national, homeland, and economic security of the nation; ensure the economic productivity of the open ocean, coasts, coastal watersheds, and Great Lakes; and improve the health of the ecosystems within them.

Understanding society's impact on the ocean and the ocean's impact on us forms the basis for ensuring a clean, healthy, and stable ocean environment that can be responsibly used and enjoyed by generations to come. This productive relationship depends on having the scientific foundation to develop and implement new strategies to enhance the health of the ocean, coasts, coastal watersheds, and Great Lakes; promote public health; and adjust resource management and use patterns. The ability to translate research results into effective decision-making tools, adapt governance structures to ensure conservation of resources, and educate and instill a sense of stewardship in the public will provide a path for a sustainable future. The purpose of this document is to develop and present ocean research priorities oriented around six societal themes that address key interactions between society and the ocean. If acted upon, these priorities will result in considerable strides toward enhancing the quality of life of the nation's citizens and safeguarding the health of the open ocean, coasts, coastal watersheds, and Great Lakes.

Community efforts, such as the USCOP, which inspired the activities to generate this plan, and the Pew Oceans Commission, produced detailed assessments of the state of the ocean and the means to address challenges revealed by these assessments. These assessments were developed using expert testimony, nationwide community input, and recommendations from previous reports. The ocean research priorities identified in this document are built on this foundation of community efforts to explore society's interaction with the ocean, to understand the impacts of human activities on the ocean, and to find new ways to restore and enhance the health of the ocean and its ecosystems.

This document considers the ocean as a dynamic global system; it does not attempt to identify research needs based on historical academic disciplines or independent activities such as resource distributions, fisheries assessments, and ocean currents. Research efforts must recognize the ocean's inextricable links to the land and atmosphere and take an interdisciplinary approach to exploring and understanding the ocean's role in many of society's most pressing challenges, such as understanding climate change and mitigating its impacts, sustaining natural resources, improving public and ecosystem health, and enhancing hazard mitigation. This document is also unique in that it recognizes the important relationship between society and the ocean and, therefore, places high emphasis on understanding the interactions between humans and ocean ecosystems—the human dimension of ocean issues. Finally, this document recognizes the unprecedented capabilities in the areas of advanced *in situ* and remotely sensed data acquisition, integration, and interpretation; information management; and computer simulation and visualization.

The national ocean research priorities described in this document build upon ocean science's strong legacy and take advantage of new interdisciplinary research approaches, sophisticated research and computational tools, and the availability of shared assets such as personnel and research platforms. An appropriately balanced research portfolio will provide insight into ocean processes that will enable better and timelier policy and resource-management decisions. These decisions will help ensure appropriate use and protection of the ocean, particularly the coastal margins, where so much of America lives, works, and plays, and that contributes so heavily to the nation's economy. This approach will require careful coordination among local, tribal, state, regional, and federal government agencies as well as academic, private sector, and nongovernmental entities. The ocean research priorities presented in this document are national in scope yet reflect the need to provide benefits at the local, tribal, state, regional, national, and global levels, while involving all parties in the enterprise.

Critical Elements

Three critical elements of science and technology will provide the United States with the scientific and technical means to redefine its relationship with the ocean for the better: developing the understanding and capability to forecast ocean processes; providing the scientific information needed to support ecosystem-based management, particularly in coastal and nearshore environments; and accelerating deployment of an ocean-observing system that will, in turn, advance both forecasting and adaptive ecosystem-based management capabilities. Aspects of these three key elements are evident throughout the national ocean research priorities identified in this document. These three elements are critical and necessary to expand society's vision of the ocean and ensure the ocean's legacy for future generations.

Developing the *understanding and capability to forecast certain ocean and ocean-influenced processes and phenomena* will change how society takes action in the future, much like weather forecasts do today. The tremendous potential of this capability has been demonstrated in the forecasts of El Niño and La Niña phenomena that are now used routinely by governments and the private sector. For example, these forecasts currently influence the buying and selling of energy resources and reduce loss by enabling agricultural interests to anticipate and prepare for El Niño-related weather hazards. These forecasts have emerged from investments in the basic understanding of equatorial Pacific Ocean circulation and its relation to weather, in observing systems capable of providing key data, and in model and simulation capability. Developing the capability to forecast key processes related to hurricane and severe-storm formation, ocean currents, fish stocks, and human-health hazards, to name a few, would expand not only the economic benefits of ocean forecasts, but their societal and environmental benefits as well.

Managing resources in ways that identify and account for the complex interactions between those resources and other components of the marine environment—including humans—is a substantial challenge. The principle of ecosystem-based management[2] is now widely recognized as one of the most effective ways to cope with a variety of increasing natural and human-induced pressures. Providing *the scientific support for ecosystem-based management* requires a multi-dimensional, multidisciplinary effort to enhance current understanding of ecosystem processes, determine which interactions are most critical, and assess the dynamics of the natural and human factors affecting those interactions, including how those factors will change in the future.

Deployment of a robust ocean-observing system that can describe the actual state of the ocean, coupled with a process to synthesize observational data, will fundamentally alter society's view of the ocean environment. Observations underpin fundamental knowledge of the open ocean, coasts, coastal watersheds, and Great Lakes. Although much work remains, communities interested in ocean research and management have developed mature plans for many components of an integrated, global ocean-observing system. Deploying the priority elements of that observing system will increase society's access to the ocean and allow researchers to enable the promise of ocean forecasting and ecosystem-based management during the next decade

Expanding the Scientific Frontier: The Need for Fundamental Science

Scientific discovery, driven by competitive, peer-reviewed investigations, is the foundation of the nation's research enterprise and is an intrinsic and highly valued component of the ocean research portfolio. Fundamental research that expands the scientific frontier enhances and deepens our understanding of the ocean and its role in the Earth system. It is essential that the nation cultivate and investigate new ideas about the ocean and new approaches for exploring the marine environment that may challenge existing interpretations. In doing so, society should recognize and even encourage risk-taking in supporting the most exciting and promising ideas for making progress in understanding the ocean. Progress requires the continued support of both systematic measurements of the ocean's properties and the freedom to pursue new ideas and technology. Discipline-oriented research focuses on examining the intricacies of one facet of science, while interdisciplinary collaborations capitalize on this focus to investigate connections and feedbacks between diverse elements. Both of these efforts need to be enhanced in parallel to enable comprehensive understanding of the ocean and its place in the Earth system. The path ahead as presented in this document necessarily includes the need for "creative individuals to pursue the kind of fundamental scientific research that can lead to unforeseen breakthroughs"[3].

The ability to access all aspects of the ocean environment, made possible by fostering scientific and technological innovation, will enable breakthroughs in basic understanding of ocean biology, chemistry, geology, and physics and the connections among these disciplines. Improved access to the open ocean, coasts, coastal watersheds, and Great Lakes depends on advances in infrastructure and technology, from advanced sensors to satellites and unmanned vehicles. The development of innovative tools, from remotely operated and autonomous vehicles, to molecular techniques and genetic sequencing, to physical, chemical, and biological sensors, will facilitate novel experiments and permit the study of processes ranging from isolated episodes to global cycles. Observing and understanding ocean processes that operate on different temporal and spatial scales and in

different regions requires a balanced combination of *in situ* observing platforms, a robust fleet of ships, remotely operated autonomous vehicles, satellites, and land-based marine laboratories supporting specialized equipment and instrumentation. The reach of ocean science research can be significantly expanded by leveraging the capabilities of other disciplines, including nanotechnology, genomics, and robotics, enabling new access to and perspectives on the ocean environment. A workforce eager to push the limits of scientific knowledge and technological innovation will support the scientific discoveries necessary to address fundamental scientific questions and to advance the use of scientific research for operational activities to help meet national needs.

The research community identifies many promising areas for scientific investment through workshops and other planning activities. The National Research Council and other community groups also publish analyses of promising new directions in fundamental ocean research that are used by funding agencies to guide investments[4]. Attempting to prioritize research efforts driven by new ideas and the desire for discovery would constrain these creative and visionary activities critical to the research enterprise. By definition, unforeseen breakthroughs and paradigm shifts cannot be planned. Therefore, this document focuses on underscoring—rather than attempting to define or enumerate comprehensively—the fundamental research efforts that provide the foundation for understanding the ocean. This document emphasizes the research efforts with particular anticipated societal applications, while invoking the fundamental research that provides the foundation for those applications.

Focusing the Nation's Ocean Research Enterprise

Framing the Approach

The scope of ocean science is to promote *discovery* that will provide new insights and perspectives on the ocean environment; impart greater *understanding* of ocean properties and processes; and expand opportunities to *apply* that knowledge to enable safe, prosperous, and sustainable use of the ocean. As the three interlinked components of the research enterprise, discovery, understanding, and application serve as the foundation for the research priorities developed in this document.

Discovery

Discovery entails both the pursuit of the unconstrained fundamental science questions (see Expanding the Scientific Frontier) that drive the imagination and the exploration of new phenomena and terrain, remote geographies, and unique marine systems. Discovery provides the foundation upon which society builds comprehension of life; it has the potential to fundamentally shift our understanding of the ocean, its role in the Earth system, and society's place in that system.

Understanding

An understanding of ocean processes is required to predict the consequences of interactions between humans and the ocean, and manage those interactions. Supported by discovery efforts, the need to understand often focuses on those processes that cascade through spatial and temporal scales, describe the interactions between ecosystem components, and/or cross thematic boundaries. Enhancing understanding is an ongoing task that requires continuous innovation in both ideas and technology. The benefit of this understanding is that new knowledge can then be applied to promote responsible use and stewardship of the marine environment.

Application

A critical component in the research process is to apply the knowledge gained from discovery and understanding to serve the public interest. Application includes efforts to translate information so that policy-makers, managers, and the public will be able to understand and use the knowledge to make informed decisions as well as provide feedback to define additional research needs. Application also includes developing new tools, new techniques, and new approaches to address complex issues and inform societal choices.

Identifying Ocean Research Priorities

This document focuses national attention on six themes that represent key areas of human interaction with the ocean.

- Theme 1: Stewardship of Natural and Cultural Ocean Resources
- Theme 2: Increasing Resilience to Natural Hazards
- Theme 3: Enabling Marine Operations
- Theme 4: The Ocean's Role in Climate
- Theme 5: Improving Ecosystem Health
- Theme 6: Enhancing Human Health

These themes and associated research priorities were developed through collaborative efforts involving all federal agencies with interest and responsibilities linked to the ocean, as well as representatives from state and local governments, academia, industry, and non-governmental organizations. For each societal theme, priorities are identified that *focus on essential research efforts that must be undertaken in the coming decade* (Figure 1). The research priorities encompass natural sciences as well as those disciplines focusing on human interaction with the ocean, such as economics and other social sciences (e.g., sociology, anthropology) and public health. In addition, tools universally critical to pursuing the

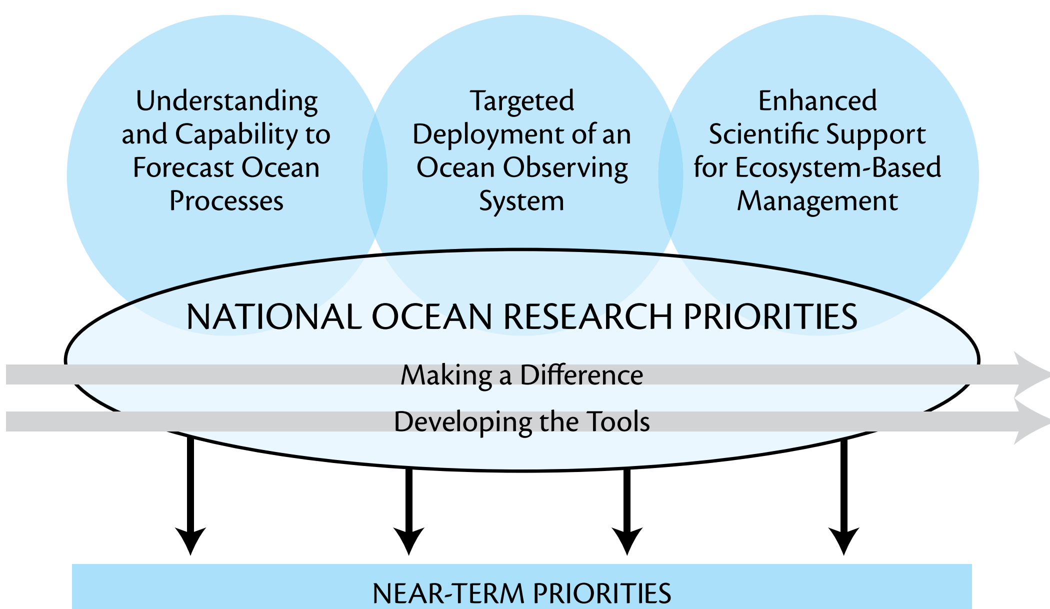


Figure 1. Overview of Ocean Research Priorities.

research priorities and realizing their results—ocean-observing and modeling capabilities, mechanisms to translate research results into effective decision-making tools, and initiatives to educate and instill a sense of stewardship in the public—are described and revisited throughout this document.

The ocean research priorities emerged from a larger suite of questions that were considered, and emphasize topics such as systems research and predictability. The following questions, with equal overall weight, were used to identify the most compelling research priorities for each theme, recognizing that the prioritization criteria for one theme may not be equally applicable to another:

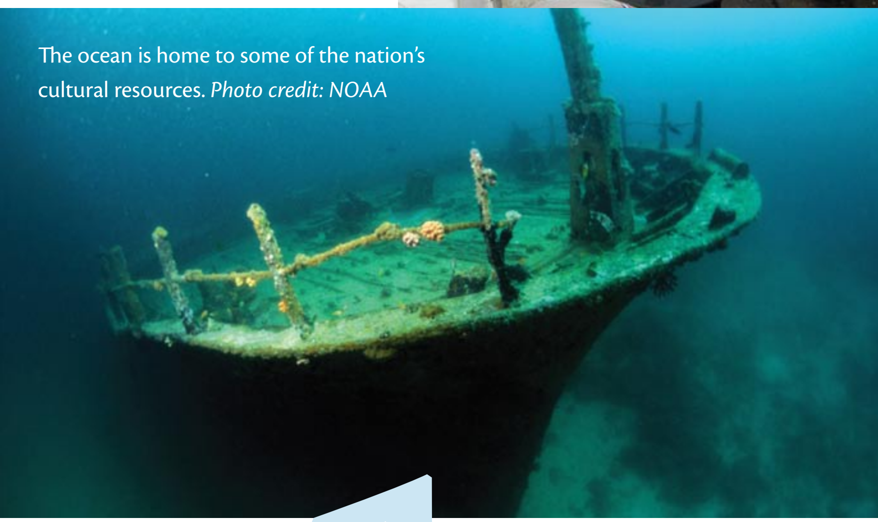
- Is the proposed research transformational (e.g., will the proposed research enable significant advances for insight and application, even with potentially high risk for its success; would success provide dramatic benefits for the nation?)?
- Does the proposed research impact many societal theme areas?
- Does the research address high-priority needs of resource managers?
- Would the research provide understanding of high value to the broader scientific community?
- Will the research promote partnerships to expand the nation's capabilities (e.g., contributions from other partners, including communities outside of ocean science, such as health science; unique timing of activities)?
- Does the research serve to contribute to or enhance the leadership of the United States in ocean science?
- Does the research contribute to a greater understanding of ocean issues at a global scale?
- Does the research address mandates of governing entities (federal agencies, state, tribal, and local governments)?

Four near-term priorities were developed to initiate rapid progress towards the 20 ocean research priorities. These near-term priorities are not a direct subset of the larger research priorities, but incorporate issues highlighted in many of them. These priorities were selected from a larger suite of efforts using the criteria above, with an added focus on impact (i.e., the value of the work), urgency (i.e., the need for a concentrated effort over the next two to five years), and partnerships (i.e., the effort will maximize collaborations among agencies and external partnerships).

Societal Themes

Fishery survey catches document the abundance and recruitment trends of species. This catch of Acadian redfish was taken in the Gulf of Maine aboard the NOAA R/V *Albatross IV*. *Photo credit: NOAA*

Energy exploration and production from the ocean represent important contributions to the nation's energy supply. *Photo credit: Department of the Interior*



The ocean is home to some of the nation's cultural resources. *Photo credit: NOAA*

Theme 1: Stewardship of Natural and Cultural Ocean Resources

The resources of the open ocean, coasts, coastal watersheds, and Great Lakes generate tremendous benefits and opportunities. The ocean is a source of food, minerals, and energy and is used for transportation, recreation, and tourism. The ocean preserves a record of the nation's cultural past. The ocean remains a vast, unexplored realm with the capacity to provide new pharmaceuticals, industrial products, and energy sources. At the same time, its resources are subject to many pressures, such as overfishing, habitat destruction, and competition with invasive species. To unlock the full resource potential of the open ocean, coasts, coastal watersheds, and Great Lakes, society must improve understanding of these resources and balance their health and use.

Rationale

U.S. waters are the source of many of the resources society uses daily. The United States has the largest Exclusive Economic Zone (EEZ) of any nation[5]. Fishery production within the EEZ and contiguous inshore waters supports a $60 billion annual seafood industry and a $20 billion recreational fishing industry[6]. Recent advances in aquaculture are providing an increasing contribution to the seafood supply. The total current market value of the oil and gas inventory is approximately $8 trillion, consisting of $1 trillion in discovered remaining reserves and an estimated $7 trillion in undiscovered, technically recoverable resources[7]. Estimates for offshore wind energy suggest a potential of 900 gigawatts within 50 nautical miles of the coast[8]. Approximately 200,000 trillion cubic feet of gas hydrate are present on land and the U.S. outer continental shelf (OCS)[9, 10]. The Great Lakes are the largest source of freshwater in the world[11]. Healthy ocean and coastal natural and cultural resources provide the foundation for a huge coastal tourism and recreation industry that is the fastest growing area of the ocean economy[12]. Prehistoric landscapes, shipwrecks, and historic and living waterfronts along the nation's coasts and Great Lakes all contribute to the national cultural heritage.

The scale and diversity of ocean resources is immense, however, resource use and development often compete with other societal needs and values. Overexploitation of many fish stocks and alteration of habitats due to human activities and/or natural influences such as climate change have had profound consequences for many ecosystems and fishing communities. Increasing domestic energy production from the EEZ (renewable and non-renewable) brings with it concerns about environmental impacts. Increasing populations at the coasts and Great Lakes impact freshwater supplies and inappropriate wastewater disposal can degrade water quality, impacting marine resources. Evaluating and addressing environmental impacts of resource use and extraction, combined with increased understanding of the factors influencing overall ecosystem health, can help balance the pressures being placed on coastal ecosystems, enable restoration of degraded habitats, and, ultimately, support robust and coordinated ecosystem-based management and governance strategies for sustainable resource use.

Research Priorities

Central to effective management of natural and cultural resources is the ability to accurately assess their current condition. This knowledge will provide the foundation to understand the complex relationships between living and non-living resources and the cumulative impacts of human activities, and help determine the likely impacts of various management alternatives. Research into issues of resource development, use, and extraction, such as exploration for mineral resources and pelagic and benthic communities, and regional variability and influence on resources, will help society prevent major impacts to ecosystems, promote sound development and use of resources, preserve cultural sites, and support management efforts to restore depleted populations to healthy and sustainable levels.

Research Priority 1: Understand the status and trends of resource abundance and distribution through more accurate, timely, and synoptic assessments.

Assessing the impacts of resource use and extraction (e.g., fisheries, ocean mining, tourism [cultural sites]) requires measuring the abundance and distribution of living and non-living resources in the open ocean, coasts, coastal watersheds, and Great Lakes. Capabilities necessary for these measurements include the ability to: assess fish-stock and protected-resource status and health; monitor living resources (spanning multiple trophic levels) nearly continuously over wide swaths of ocean at appropriate levels of species resolution; assess the spatial and temporal variability (both natural and use-induced) of resources (e.g., biota, energy, minerals, and pharmaceuticals), including in deep-water settings; and provide long-term and sustained monitoring and mapping of natural and cultural resources. Development and implementation of these capabilities will enable adaptive approaches to the management of natural and cultural resources, using empirical evidence to design and modify management efforts (e.g., individual harvest quotas, special use areas, marine protected areas [MPAs]) to be most effective.

Research Priority 2: Understand interspecies and habitat/species relationships to support forecasting resource stability and sustainability.

Understanding the individual and cumulative impacts of an ever-widening array of human activities (e.g., transportation, recreation, land use, fishing, energy exploration and development, and increased food production from aquaculture) on water and habitat quality and the ocean's ability to support marine life and biodiversity is necessary for enabling ecosystem-based management approaches to ocean-resource use. Often the data necessary for these assessments are difficult to obtain because of practical limitations of controlled experimentation and replication in natural systems. Investing in observations, process studies, and advanced modeling will expand current understanding of impacts at appropriate temporal and spatial scales, and help identify crucial data and process-understanding gaps such that the proper resource-management techniques can be developed and implemented. Priorities to enable improved natural-resource forecasting include: (1) development and validation of ecosystem and species interaction models at appropriate scales that incorporate feedback mechanisms among trophic levels; (2) assessments of regional and local models of environmental changes (e.g., responses to annual, decadal, and longer-term climate drivers; rapid regime shifts; hydrodynamic circulation; watershed discharge) to help determine how these changes impact resources; (3) development of approaches and scenarios to understand and integrate the specific and cumulative impacts of various natural resource policies on living resources and human communities (incorporating improved assessments of impacts on ecosystems [see Improving Ecosystem Health]); and (4) collection of necessary data (observational and experimental) to support model robustness.

Research Priority 3: Understand human-use patterns that may influence resource stability and sustainability.

Determining the "worth" of natural and cultural resources and evaluating effects of alternative management scenarios requires considering economic (i.e., market and non-market valuation), sociological, and cultural factors, and potential competing uses, in addition to ecological factors. These assessments will also support evaluations of the socioeconomic trade-offs inherent in management efforts. Human-use data can be acquired through expanded surveys and analysis of economic and sociological factors associated with a broad range of open ocean, coast, coastal watershed, and Great Lakes resource activities. The use of geocoded socioeconomic data (e.g., resource cost and earning, demographics, income), combined with new methods to assess non-market valuation (see Improving Ecosystem Health), will enable the integration of socioeconomic and natural processes into models to determine interactions between these systems. Human behavior and economic research, combined with resource-use assessment and modeling, will help support effective evaluation of the success of various management options on resource use and sustainability.

Research Priority 4: Apply advanced understanding and technologies to enhance the benefits of various natural resources from the open ocean, coasts, and Great Lakes.

Key technological developments are required to facilitate long-term and effective resource management; to make more responsible use of available sustainable and non-sustainable resources, such as energy, minerals (including sand), and pharmaceuticals; and to support alternatives to resource extraction (e.g., aquaculture, alternative energy sources), in conjunction with efforts to enhance the efficacy of and limit impacts from marine operations. Areas of focus include, but are not limited to: development of sustainable approaches to aquaculture that consider implications for surrounding ecosystems, wild genetic resources, and impacts on coastal economies; advancement of new sustainable energy technologies from the ocean, including efficient methods for power generation (e.g., wind and tidal power), and scientific information to fully consider impacts on marine life; development of new generations of military subsurface detection systems or other mitigation methods that are less deleterious to species sensitive to acoustic emissions in certain sound ranges; development of bycatch-reduction technologies for fisheries and protected resources (e.g., seabirds), enabling sustainable resource use; and use of advances in exploration technologies (e.g., geospatial, biooptical) to map and characterize the EEZ and the U.S. continental shelf, to establish the outer limits of the U.S. continental shelf where it extends beyond the limits of the EEZ, and to assess its important ecological and economic resources.

Necessary Tools

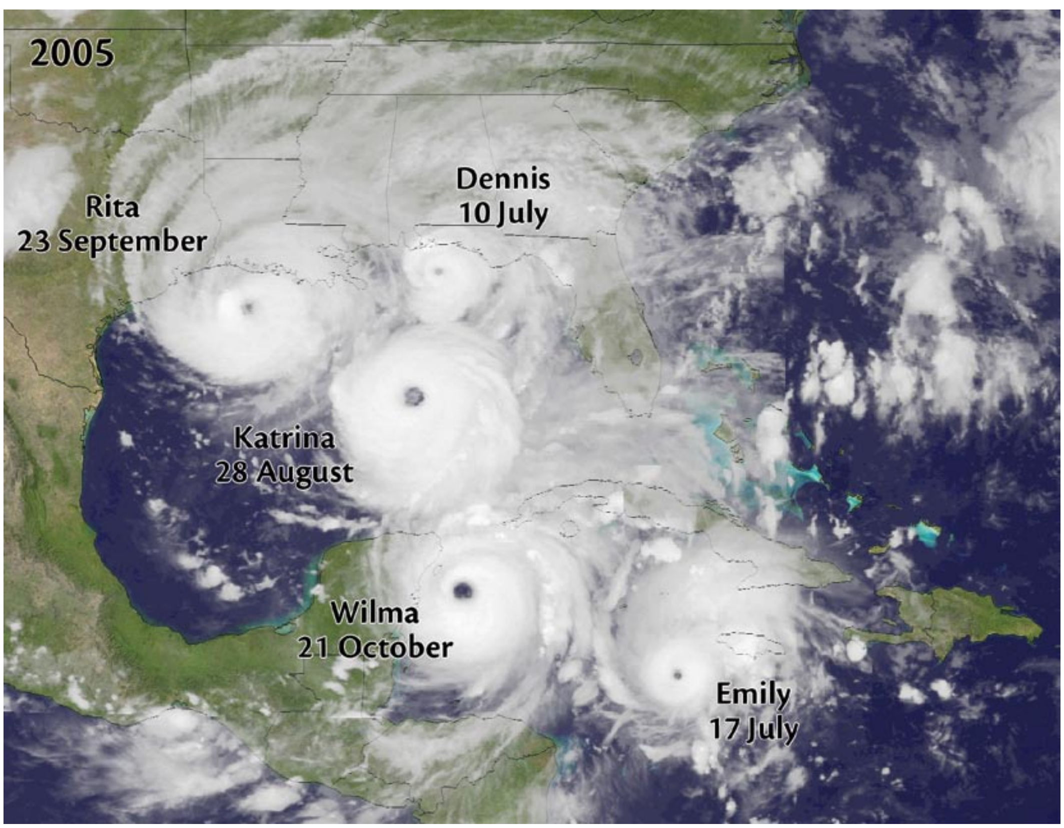
Technologies and procedures will be needed to enable rapid, efficient, and synoptic assessment of ocean resources (including inventories and alterations). An expanded and technologically more capable domestic fleet of ships would improve the capability to provide important information on the status of managed populations and ecosystem effects of human populations. Additionally, improved remote-sensing tools are needed to obtain necessary biological (e.g., biomass) and physical (e.g., current direction, wave height) parameters, and to survey deep waters, particularly as energy exploration moves to the edges of the OCS. Advances in unmanned aerial and autonomous vehicles will aid in collecting synoptic resource information. In addition to monitoring and assessment with existing technologies, new and improved technologies and protocols are needed to expand the capabilities of fixed and mobile observing platforms to include biological and chemical sensors, and advanced acoustics and mapping capabilities.

Enhanced information-technology and data-support infrastructure are essential. Comprehensive environmental databases with appropriate spatial and temporal resolution that integrate information from local, regional, national, and global sources are key to understanding ecosystem interactions and providing the necessary information for effective and adaptive resource management. Information systems using geographic information systems (GIS) can integrate diverse data sets (e.g., physical, biological, social, cultural) to promote spatial analysis and static and dynamic modeling. Development of integrated ecosystem assessments will, in turn, expand understanding of interrelationships among the physical environment, ecosystems, and human activities.

Implementation of these new approaches requires more technical and scientific personnel skilled in diverse disciplines, including natural sciences, social sciences, and information technology for the operation, maintenance, and interpretation of information. Investments in training and maintaining this workforce are key priorities for next-generation, natural-resource decision-support systems, improved resource management, and decision-making.

Theme 2: Increasing Resilience to Natural Hazards

Recent hurricanes and tsunamis have clearly demonstrated the potential for natural disasters to have economic, environmental, social, and public-health impacts on regional, national, and global scales. Communities, maritime operations, cultural resources, social services, and ecosystems are vulnerable to coastal and marine physical hazards. Although society cannot eliminate natural hazards, their impacts can be reduced. Sustained and coordinated investment in research and technology will provide the knowledge and information base needed to assess and reduce risk, save lives and property, ensure more rapid recovery and effective mitigation, and develop informed and effective responses to future hazard events.



Understanding the impact of severe storms on coastal regions is critical to improving hazard resilience. *Composite photo: University of Wisconsin - CIMSS Tropical Cyclones Group, NOAA, NASA.*

Rationale

With over 50 percent of the U.S. population living in coastal counties and that number rising each year[13], the United States must be adequately prepared for coastal disasters. Even as the nation continues to direct significant federal funding toward science and technology to assist in reducing the impacts of natural hazards, the United States still faces enormous losses each year from ocean and coastal hazards, including:

- Severe storms, hurricanes, and tornados, and the associated coastal and offshore wind, wave, and current damage
- Coastal inundation and flooding from storms, tsunamis, and regional meteorological events
- Earthquakes, landslides, and volcanic eruptions along the coast and offshore, and resulting tsunamis

The costs of these events are significant and will likely increase. In 2005, Hurricane Katrina devastated the Gulf Coast and is estimated to be the costliest natural disaster yet to strike the United States[14]. The potential short-term and long-term human and economic costs, including impacts to public health, threats to subsistence, disruption of livelihoods, population relocation, infrastructure damage, and ecosystem degradation, to at-risk regions from tsunamis (Pacific Northwest, Alaska, Hawaii, southeastern United States, Caribbean) are substantial.

Effective response to natural hazards is impeded by limitations in the ability to comprehensively assess hazard potential, vulnerability, and risk. Human and natural processes (e.g., land development, sea-level rise) constantly alter system vulnerability and the risk of hazards to coastal communities. To reduce the social and economic impact of natural hazards, the public and decision-makers must be educated about the risks, associated impacts, and response costs of natural hazards. A sound scientific and technological basis for decision-making must include improved models of hazard impacts, more accurate and timely forecasts, and comprehensive assessments of future hazard potential, vulnerability, and risk.

Research Priorities

Hazard assessments must be comprehensive, reflecting multiple hazards and their impacts on diverse economic, social, and ecosystem sectors. Physical processes must first be assessed and then coupled with improved understanding of the role of social systems and human behavior in increasing vulnerability or enhancing resilience. This effort will be enhanced by investigations of ecosystem health (e.g., in response to resource and land use), impacts of climate change (e.g., sea-level rise, storm intensification and/or concentration), and direct and indirect risks to public health that broadly influence hazard resilience. Assessment of hazard impacts and risk that incorporate improved hazard understanding, effective research translation, communication, and education, are integral for developing a "risk-wise" population, supporting cost-effective strategies designed to increase resistance, enhancing resilience to hazards, and promoting avoidance.

Research Priority 5: Understand how hazard events initiate and evolve, and apply that understanding to improve forecasts of hazard events.

Quantifying future hazard potential requires understanding hazard generation (e.g., storms, submarine and coastal landslides, tsunamis, flooding) and past hazard occurrence. Enhanced hazard forecasts, particularly of storm formation, track, intensity, and associated waves, surge, and flooding, will support more effective responses to developing hazard events. Research in this area should focus on process studies and development and validation of models of hazard generation (e.g., tsunami-source modeling, seafloor-stability modeling, storm formation) and evolution (e.g., tsunami propagation, storm and inundation modeling). Probabilistic models and assessments of hazard potential should include effects of land subsidence and future climate change (e.g., changes in storm intensity or frequency, sea-level rise, landscape change) on hazard potential and vulnerability.

Research Priority 6: Understand the response of coastal and marine systems to natural hazards and apply that understanding to assessments of future vulnerability to natural hazards.

Natural hazards impact infrastructure directly through alterations to the underlying landscape and through secondary processes (e.g., slope failures, shoreline change, inlet formation, coastal erosion, sediment transport, flooding). Natural hazards have significant impacts on coastal features, such as shorelines, as well as cascading and nonlinear impacts throughout ecosystems, during and after the hazard event. Natural systems, such as wetlands and reefs, play a significant role in coastal resilience. Understanding the capacity of these systems to mitigate the effects of natural hazards, how altering the system (i.e., through physical destruction, sediment diversion) affects this capacity, and understanding

altered ecosystem dynamics and processes, will improve the ability to facilitate recovery of ecosystem functions and to undertake appropriate restoration efforts. Priorities include understanding and modeling landscape change (including impacts/influences across the adjacent watershed) associated with coastal hazards, determining structure and infrastructure resilience, and assessing vulnerability of coastal communities, public health, infrastructure, marine operations, and ecosystems. Models based on observations of pre-event conditions and post-event impacts are required to forecast the magnitude and nature of impacts, the changing vulnerability of the altered landscape, such as the influence of land use and restoration on a system's ability to resist or adapt to hazards, and the long-term impacts on ecosystem functions and health.

Research Priority 7: Apply understanding to develop multi-hazard risk assessments and support development of models, policies, and strategies for hazard mitigation.

Integrating observations, data, and models will enhance understanding of hazard potential and vulnerability, and improve risk assessments for coastal communities, public health and safety, infrastructure, marine operations, and ecosystems. Research efforts must identify vulnerable ecosystem functions and infrastructure components, determine the potential for cascading component failure, and assess the efficacy of natural (e.g., barrier islands, coastal wetlands) and engineered systems (e.g., hurricane barriers, levees) in hazard mitigation. These assessments should be integrated with improved understanding of system responses to hazards and incorporated into comprehensive risk assessments. These risk assessments will support identification of effective and affordable systems, materials, and technologies for hazard-resilient and resistant communities, infrastructure, and ecosystems as well as support development and management approaches minimizing hazard impacts.

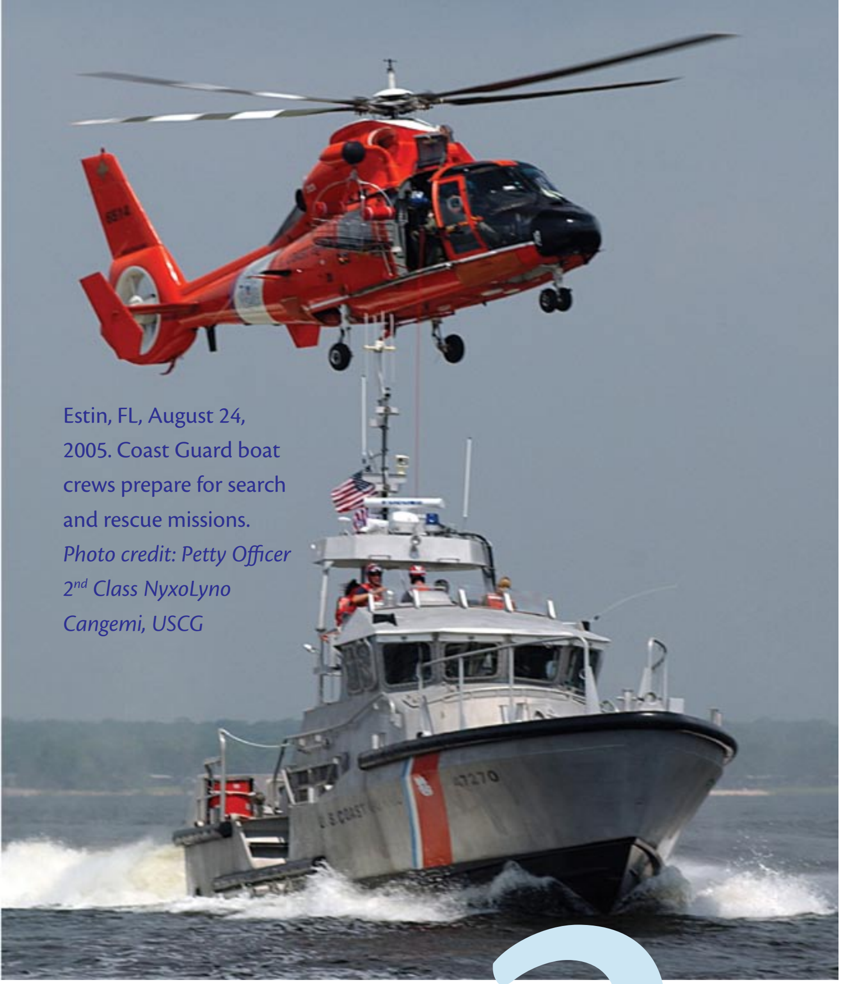
Models of resilience and resistance to hazards must also address social and economic drivers that influence pre-hazard activities (e.g., land use, shoreline development) and responses to hazards (e.g., warning responses, community development, economic restructuring). Integration of models and risk assessments into decision-support tools will inform short- and long-term public and policy responses to hazards that will minimize economic, social, and environmental costs associated with natural hazards. Integrating natural and social sciences will ensure that hazard products and policies address public perceptions of risk, communicate the consequences of community and individual responses to immediate and long-term hazards, and enhance appropriate public response to hazard assessments and warnings at all levels ("risk-wise" behavior).

Necessary Tools

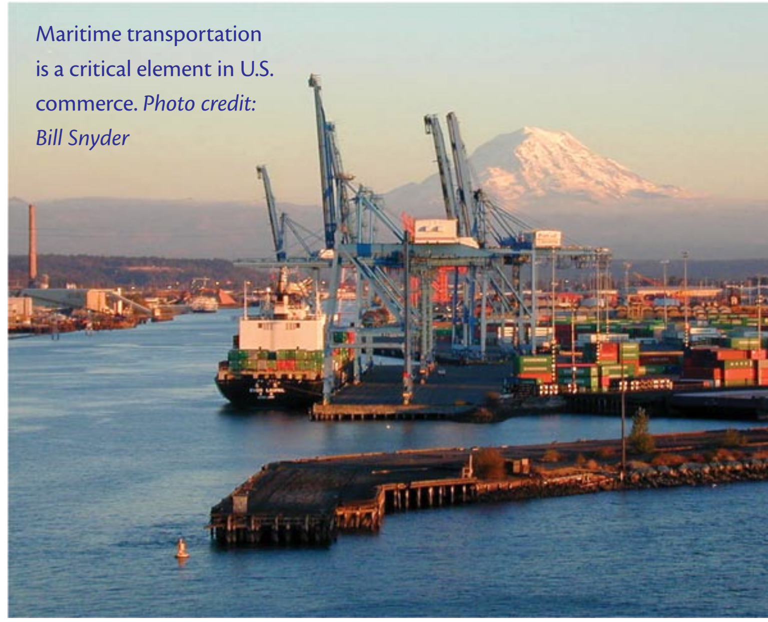
Meeting the broad requirements necessary to reduce hazard impacts and increase hazard resilience will require continued expansion of existing observational systems, data-delivery systems, and modeling capabilities at regional, national, and global scales. Sustained and integrated marine and coastal observations, including technological improvements in remote and *in situ* sensing of multiple time-sensitive parameters (oceanographic, geophysical, hydrological, chemical, biological, geographic) are required. Comprehensive geospatial characterization combined with sustained and reactive deployment modes of operation are required to acquire baseline (pre-impact) and post-hazard data. Deployments must be capable of assessing diverse hazard processes and impacts, such as coastal and inland inundation and water quality. These deployments would support development of improved models of, for example, storm evolution and coastal response. The capability to provide up-to-date characterization of coastal vulnerability and pre-storm conditions (including topography and bathymetry, land-use/land-cover, monitoring of riverine and coastal water levels) must be maintained.

Multi-hazard assessments will require information infrastructure supporting development of an "all-hazard" GIS resource with defined standards supporting information integration and application. Advanced computational resources and the establishment of community computational standards are required for data-assimilation systems, coupled land-ocean-atmosphere models, and data management and delivery systems. The design and implementation of robust, reliable, and widely available notification systems will help enable more effective communication of warnings.

Research communities that address hazards currently focus on single hazards, single elements of the hazard cycle (e.g., generation, impact, policy), or single research disciplines (e.g., physical, ecological, social, and engineering sciences). These diverse communities must be coordinated and integrated to inform and evaluate mitigation strategies with the broadest consideration of costs and effectiveness (i.e., on economic, sociological, ecological levels). An integrated approach will lead to more effective translation of research results and development of tools for informed and comprehensive decision-making.



Estin, FL, August 24, 2005. Coast Guard boat crews prepare for search and rescue missions. *Photo credit: Petty Officer 2nd Class NyxoLyno Cangemi, USCG*



Maritime transportation is a critical element in U.S. commerce. *Photo credit: Bill Snyder*

3 Theme 3: Enabling Marine Operations

Marine operations are essential components of the global economy and vital elements of economic prosperity, national security, and homeland defense[15]. Marine operations require freedom of navigation in the global ocean and the ability to conduct mapping and charting activities, gather tide and current information, and use U.S. ports, harbors, estuaries, and the Great Lakes. Marine operations also deal with issues such as bridge clearance, dredging, navigation aids, and ice coverage. Forward-thinking, innovative research, coupled with technological advances, will permit marine operations to meet challenging requirements for increased levels of transportation and commerce in the maritime domain and to address security concerns, while balancing sustainable use and protection of the environment.

Rationale

Marine operations comprise a broad set of activities, including merchant ship traffic, commercial fishing, marine public transportation, and military operations that occur in the open ocean, coasts, coastal waterways, and Great Lakes. Even a brief interruption in marine operations can have serious consequences for many sectors of society, national security, and the U.S. economy. The broad scope and far-reaching impact of marine operations requires expanding knowledge in several key areas. Though the priorities identified in this theme emphasize the transportation sector, the knowledge derived from these efforts will have broad applicability in other operational areas, such as national security (see Box 1).

Given that the majority of the nation's commerce (by weight) travels through U.S. ports and is anticipated to expand, including increased volume of open-sea shipping (potentially through an ice-reduced or ice-free Arctic[16]) and short-sea shipping[17], the capacity of the U.S. marine transportation system must be enhanced[18]. With that expansion, projections state that trade will increase, ships will become larger, and population along coasts will grow, all of which will have impacts on the marine environment and the nation's ability to conduct marine operations.

The United States has more than 90,000 miles of shoreline, 25,000 miles of navigable waterways, and 3.4 million square miles of open water within the U.S. EEZ[19,20]. Safe and effective navigation of harbors, ports, and waterways by various users requires reliable weather and sea-state forecasts and up-to-date maps and charts.

Numerous other commercial but non-transportation uses of the maritime domain exist, including offshore aquaculture, energy extraction/harnessing (i.e., facilities for oil, gas, and wind), seabed and mineral-rights uses, and laying of subsea communications and cables, all of which greatly affect the environment and use of the maritime domain. Resolving conflicts among the numerous existing and emerging uses of the maritime domain represents a challenge. To properly address these issues and to use the results of the research outlined below effectively requires improved communication and collaboration among the diverse stakeholders involved in marine operations, including industry; local, tribal, state, and federal governments; and researchers.

Research Priorities

Increased understanding of the environmental impacts of marine operations and the environmental conditions affecting marine operations is necessary as these activities expand (e.g., increased oil and gas development, aquaculture, transportation, and other ship operations in the open ocean and close to shore [e.g., military, search and rescue]). This increased understanding is necessary to ensure a balance of operations and environmental protection. Additionally, more effective collection, processing, and modeling of environmental data are required to ensure safe and secure operations.

Research Priority 8: Understand the interactions between marine operations and the environment.

Central to enabling effective and environmentally viable marine operations is understanding how marine operations (including port development and vessel maintenance and operations) affect the environment, and how environmental conditions affect operations. This understanding will be particularly important in environmentally sensitive areas such as the Great Lakes, coastal areas with low tidal exchange, and coral-reef systems. Areas of study include the release, dispersion, cycling, and cumulative ecological impacts of contaminants (i.e., from oil spills and releases, air emissions); interactions with marine life (e.g., bird migration, ship strikes, ocean sound); impacts of aquaculture development and production; factors contributing to the introduction and persistence of invasive species (e.g., ballast water); and effects of expanding transportation routes (e.g., Arctic routes). These research efforts will build upon investigations into factors influencing ecosystem dynamics (e.g., invasive species, contaminants) and sustainable resource use (e.g., impacts on wild stocks from aquaculture). They will also enable the development of mitigation strategies and technologies (e.g., passive sonar, spill prevention and containment, ballast-water treatment, vessel routing to avoid ship strikes).

Research is also needed to address the feedback effect of environmental conditions on marine operations. Such research includes refining sediment transport models to enable rapid, efficient, and environmentally sustainable dredging and dredged-material management. Investigations of environmental changes related to climate change (e.g., sea-level rise, sea-ice abatement[21], lake-level decreases) will help determine impacts on the development of alternative transportation routes, necessary changes to ports and harbors, and the stability and safety of energy-extraction platforms.

Research Priority 9: Apply understanding of environmental factors affecting marine operations to characterize and predict conditions in the maritime domain.

Enhancing environmental observation, characterization, and forecasting of ocean and waterway conditions (e.g., currents, turbidity, surface waves, sea-ice extent, lake levels, biogeochemical conditions) across the global ocean (open ocean, coasts, coastal waterways, and Great Lakes) is necessary for safe and efficient marine operations. Increased precision in forecasting marine conditions (e.g., improved real-time, ocean-current models; storm-surge projections, in conjunction with efforts to address natural hazards) will promote safe and efficient operations, including transportation, military operations, and search-and-rescue efforts, and will minimize negative impacts on marine operations and the environment. Technologies (e.g., robust sensors and infrastructure, autonomous vehicles) must be developed to enhance data collection in all weather conditions to support high-spatial-resolution and near-real-time forecasting throughout the open ocean and coastal zone.

Research Priority 10: Apply understanding of environmental impacts and marine operations to enhance the marine transportation system.

As commerce increases, the capacity of the marine transportation system must also increase through improved waterway traffic mobility and safety, enhanced port operations and productivity, expanded capabilities (e.g., short-sea shipping, higher-capacity vessels), and reduced congestion. Effective seaport planning, including port development, expansion, or modification and coordination with land and air transportation routes, and waterway improvements, must incorporate environmental impacts, social and economic drivers, and operational needs. Social and economic assessments that address human demographics, land use, income, and output must be developed and incorporated into risk assessments and models that address environmental impacts of marine operations (e.g., benthic disturbance, contaminant releases, impacts from invasive species) and operational requirements (e.g., port and waterway depth and capacity). These models can be used to design the safest and most effective and environmentally sustainable mechanisms to expand the operational capacity of the marine transportation system.

Box 1. Ensuring National and Homeland Security

The coast and open ocean are critical domains for the security of the United States, both at home and abroad. National-security operations in the ocean take place globally and often require continuous, near-real-time monitoring of environmental conditions using tools such as autonomous sensors, targeted observations, and adaptive modeling. Expanded awareness of the ocean environment for security operations requires improved capabilities in:

- Autonomous monitoring of desired ocean parameters in any location for extended time periods
- Integration of multi-sensor data, including data from a robust, satellite-based global earth observation system
- Numerical models to provide nowcasts and forecasts for critical parameters.

These capabilities, combined with improved understanding of the ocean environment enabled by other ocean science research activities, will support accurate ocean-state assessments and allow future forces to conduct joint and combined operations in nearshore and deep-ocean operating environments, anywhere and at anytime.

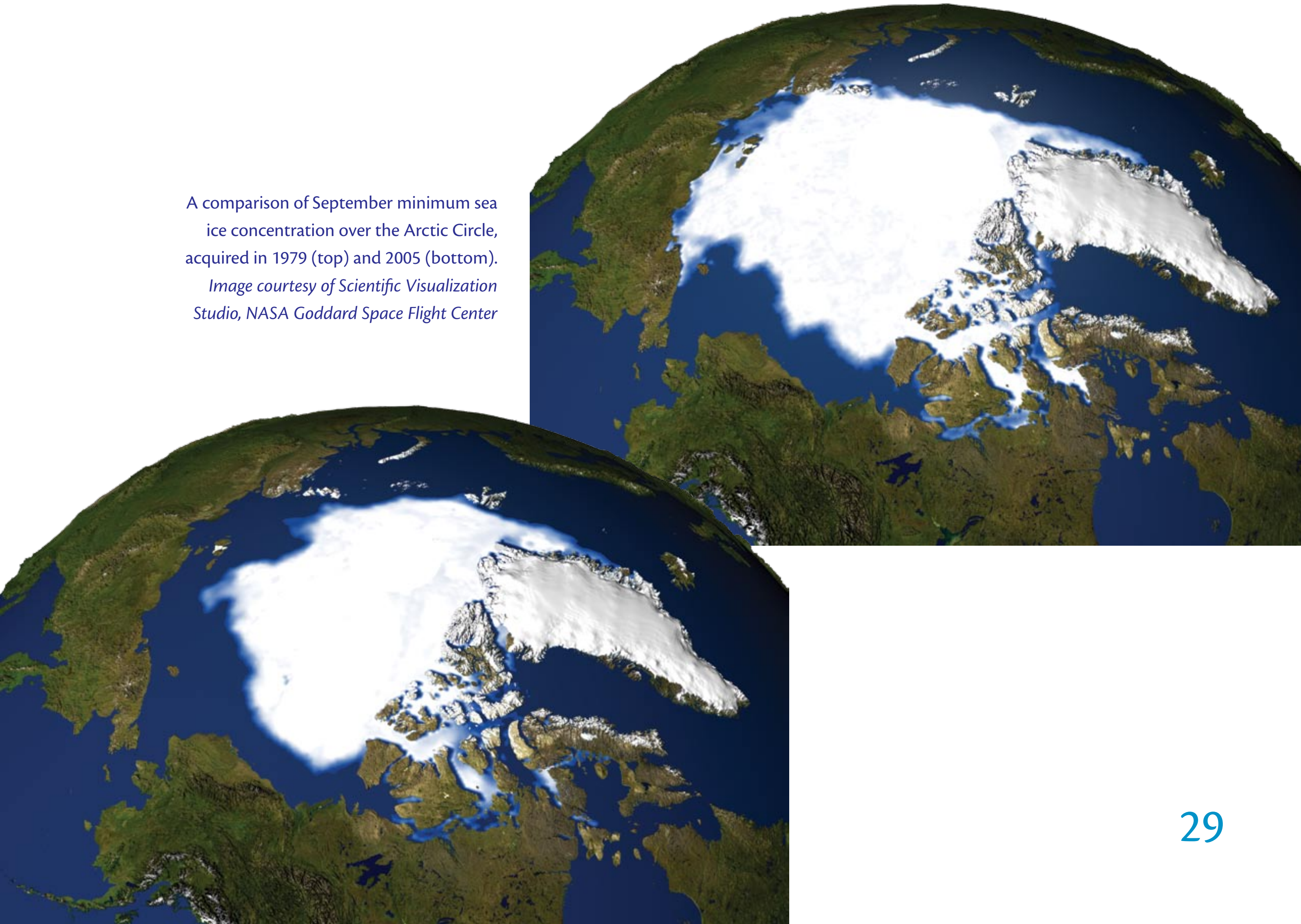
Necessary Tools

Achieving safe, effective, efficient, and secure marine operations that support environmental protection requires a diverse suite of infrastructure and technology, ranging from assessment methodologies (e.g., rapid-assessment methods for detecting marine contaminants/pollutants and harmful, non-indigenous species) to observing systems and information networks. Providing accurate and comprehensive environmental information will require expanding observational networks to monitor, record, and present real-time, surface-monitoring data (e.g., high-frequency, coastal-based radars). This expansion will require advancing sensor and technology development, particularly for autonomous and persistent observations, as well as for long-term observing systems; expanding real-time or near-real-time data collection on environmental variables by incorporating observational capabilities of ships of opportunity (e.g., fishing, cargo, and passenger vessels); and enhancing automated and autonomous bottom-mapping capabilities for change detection to improve rapid, full-scale survey scheduling.

Data collected by the observing systems must be accessible through a comprehensive national data network, either through a single system[22] or a distributed network. Developing this data network will require new methodologies that address gaps in data collection, sharing, and interoperability of technologies, and should permit integration of existing research into operational systems (e.g., systems providing real-time navigation data to vessels). This data network should be able to link with other databases, such as those focusing on ecosystem data, and developed in accordance with international standards for data exchange. The national data network will also provide the data needed for models simulating multiple scenarios to better understand potential impacts weather events or man-made disruptions on marine operations, and to support operations restoration plans.

Theme 4: The Ocean's Role in Climate

The ocean plays a fundamental role in governing climate through its capacity to store and distribute heat and carbon. The challenge is to accurately assess the ocean's past and present state, processes, and phenomena influencing climate, and society's influence on them, and to improve predictions and projections of climate change. These predictions and projections will improve society's ability to respond to and reduce, where feasible, climate-related hazards; to adapt to climate change and variations (e.g., sea-level rise, changing weather patterns); and to inform management and policy decisions addressing human and environmental impacts.



A comparison of September minimum sea ice concentration over the Arctic Circle, acquired in 1979 (top) and 2005 (bottom). *Image courtesy of Scientific Visualization Studio, NASA Goddard Space Flight Center*

Rationale

The ocean covers more than 70 percent of the planet and has a much higher capacity to store heat than the atmosphere. Imbalances of the planetary energy budget are manifested in changing ice conditions and ocean temperatures. Runoff from melting ice sheets and glaciers and an expanding water mass due to increasing temperatures lead to rising sea levels. Low-lying coastal regions are particularly impacted by gradual sea-level rise in addition to episodic events (e.g., storm surges, coastal flooding). A more complete understanding of how changing sea level impacts coastal communities is needed at regional, state, and local levels.

The tropical ocean is a vital component of seasonal-to-interannual climate variability. For example, the El Niño-Southern Oscillation is known to have a substantial impact on many regions of the world, influencing agricultural yields and hurricane intensity. Current evidence suggests that the tropical ocean also influences the occurrence of multi-year droughts. The global ocean is also an important component of the global water cycle; it receives and redistributes freshwater from rivers and ice discharge, and provides moisture (through evaporation) to the atmosphere that precipitates over the ocean and continents. Alterations in large-scale ocean circulation can influence long-term climate change and, possibly, short-term or abrupt changes.

Recently, changes in major ocean processes have been demonstrated to affect marine ecosystems, causing, for example, large swings in the populations of commercial fisheries, changes in seabird-population distributions, and coral-reef-bleaching events. Warming oceans have resulted in changes in the distribution and abundance of populations (e.g., at the poles, in temperate regions, and in coral-reef habitats). The future amount of greenhouse gases in the atmosphere, such as carbon dioxide (CO_2) and methane, will depend, in part, on the exchange of these gases in open-ocean and coastal systems (e.g., wetlands). Substantial changes in ocean chemistry as a result of oceanic uptake of these gases will further influence ecosystems and their processes. For example, rising atmospheric CO_2 levels are lowering ocean-water pH. A more acidic ocean affects calcifying organisms, such as corals, with significant effects to reefs, the ecosystems they support, and their ability to protect vulnerable coastlines. The growing body of knowledge about the impact of climate on marine chemistry and ecosystems will also enhance ecosystem-based management efforts.

The ocean has a controlling influence on the path and intensity of major storm systems, such as hurricanes, mid-latitude winter storms, and intraseasonal atmospheric oscillations. Improved understanding of the drivers of these systems resulting in predictive capability will enhance society's ability to prepare and adapt cities and other public infrastructure for the inevitable arrival of severe events and to take advantage of opportunities presented by climate predictions.

Research Priorities

Consistent with the scientific challenges identified in the *Strategic Plan for the U.S. Climate Change Science Program (CCSP)*[23], it is essential to improve understanding of the ocean's role in past, present, and future climate and to educate decision-makers and the public about this role. Phenomena that contribute to climate change and variability include large-scale, long-term coherent variability (e.g., Pacific Decadal Oscillation [PDO], North Atlantic Oscillation [NAO], Atlantic Meridional Overturning Circulation [MOC]); large-scale, nonlinear behavior (e.g., abrupt changes in large-scale ocean circulation); and ocean-atmosphere fluxes (i.e., of carbon, momentum, heat). Applying improved understanding of the ocean's past and present role in climate change and variability will enable better predictions and projections of climate effects on ocean processes and components (e.g., ecosystems). This understanding will help inform current and future management efforts, including coastal land use and development, and alternative energy use and development (e.g., wind and tidal power). A pressing barrier to improved understanding and an item for immediate attention is the lack of sufficient observing capabilities. Determining impacts on the ocean from climate changes, including identifying impacts associated with natural variability and anthropogenic influences, as well as the effect of ocean processes on climate, will be enhanced through coordination of efforts from other societal themes (e.g., factors influencing ecosystem health, natural-resource use, natural-hazard mitigation, impacts to marine operations, and efforts to protect public health).

Research Priority 11: Understand ocean-climate interactions within and across regions.

Ocean regions, such as tropical, polar, and deep sea, can exert powerful influences on, and in turn, be influenced by, climate change. Current understanding of the type or temporal and spatial extent of this influence is limited. Improved short-term climate predictions require a more complete understanding of the influence of global tropical ocean phenomena (as demonstrated by El Niño, PDO, and NAO events and monsoons in the Indian and eastern Pacific Oceans). Increasing global temperatures could lead to an ice-free Arctic Ocean in summer, with potentially widespread impacts, such as changes in polar albedo and ocean-atmosphere heat exchange, alterations in sensitive Arctic ecosystems, and development of new shipping routes (see Enabling Marine Operations). A warmer Arctic can contribute to coastal flooding due to melting ice sheets, and may influence abrupt or longer-term climate change. At the opposite pole, the Southern Ocean is a region of significant biological productivity, CO_2 uptake, and large-scale ocean circulation forcing, with significant climate implications. Finally, the role of the deep ocean must be ascertained, particularly with regards to mitigating climate change (e.g., via carbon sequestration and heat storage). Processes within these regions (e.g., ocean circulation, air-sea interaction, convection, water-mass formation) can have a variety of individual and compounded impacts over many spatial and temporal scales, ranging from regional effects of sea-ice diminishment on Arctic ecosystems to global effects of sea-level rise.

Research Priority 12: Understand the impact of climate variability and change on the biogeochemistry of the ocean and implications for its ecosystems.

Changes in physical properties of the ocean (e.g., heat, freshwater and circulation), as well as biogeochemical properties (e.g., carbon, nitrogen, dust, trace elements, pollutants), can have a variety of impacts, particularly on ecosystems, ranging from coastal watersheds, to shallow and deep-water coral reefs, to open-ocean systems. For example, increasing ocean acidity, altered biogeochemistry, changing current patterns, loss of sea ice, rising sea levels, and modified salinity and sea-surface temperature may irreversibly alter ecosystems. Sustained observations (e.g., global and coastal observatories), process research (e.g., air-sea exchange, ecosystem interactions) and modeling (e.g., coupled models integrating global and regional biological, chemical, and physical data) will help determine fluxes and cycling of biogeochemical variables and help identify and quantify impacts on ecosystems of the greatest importance. These efforts will also help identify subsequent feedbacks regarding the influence of ecosystems on climate (e.g., influence of ocean acidification on carbon uptake and sequestration, desertification, increasing iron dust and subsequent oceanic algal blooms). This effort will serve to support effective management of these ecosystems so that they remain healthy and viable, in conjunction with research examining impacts to and influences on ecosystem health.

Research Priority 13: Apply understanding of the ocean to help project future climate changes and their impacts.

The ocean is getting warmer, more freshwater is being added by melting ice sheets, and more CO_2 is being absorbed from the atmosphere. The ability to predict the timing and magnitude of climate changes due to these and other processes and to understand how such changes will impact society will be enhanced by quantifying the predictability of these processes and increasing temporal and spatial resolution and dynamical complexity of global ocean models. Integrating expanded global and regional ocean observations, coordinated paleoceanographic data and assessments, and enhanced process research into global coupled ocean-ice-atmosphere-land climate models will help determine the past and present influence of ocean processes on climate change, including the potential for rapid or abrupt change (e.g., "tipping points"). Coupled climate models will support improved short-term predictions (e.g., hurricane intensity) and long-term projections (e.g., sea-level rise) that will enable local, tribal, state, regional, and federal policy- and decision-makers to plan for and adapt to effects of climate change.

Necessary Tools

The continuing challenge for climate-related ocean research remains the lack of a robust, integrated system of global ocean observatories (based on quantitative design studies) capable of sustained observations and integrated with international observing efforts. The development of coastal and coastal watershed observing systems is integral to this effort. Observations from the individual components of this system (including *in situ* and remote [e.g., satellite] sensors) must be integrated through data management and communication capabilities that provide open access, searchable content, and routine delivery to all users. In addition to collecting physical, biological, and biogeochemical data, the observing-system effort should include the capability to integrate with future observing systems and incorporate data collected outside of this effort (e.g., sediment and ice-core paleoceanographic data) into a larger database. The databases from these systems should be integrated with the global system. Data systems should have the capability to develop climate-data records for physical and biogeochemical data sets and to reconstruct past ocean states, including the development and refinement of climate proxies.

Ocean and coupled climate model improvements will be necessary to integrate large volumes of observational data and reconstruct past ocean states and predict future states. Increased computational capabilities, including versatile software, efficient algorithms, focused resolution, and capacity, are required to support these advances in data and modeling capabilities.

Sustained and improved satellite and *in situ* sensors are necessary to collect information for a sufficient time period to be able to detect subtle, background climate trends over a broader range of climate parameters, such as currents, salinity, and sea-ice thickness, to draw a more complete picture of fundamental climate processes. Next-generation, *in situ* chemical and biological sensors that collect a variety of information, including data on sentinel organisms and habitats, will also be important. This enhanced data collection must be accomplished while maintaining long-term climate records of key variables.

The nation's coastal ecosystem provides a complex array of goods and services, and is influenced by a multitude of climatic and human factors. *Graphic credit: NOAA*

Theme 5: Improving Ecosystem health

Multi-faceted and complex, marine ecosystems, including the open ocean, coasts, coastal watersheds, and Great Lakes, provide a wealth of benefits to humankind. They are also finite and vulnerable to overuse or misuse from human activity and impacts from natural events. Comprehensive, well-focused, interdisciplinary research can provide the information needed to balance competing uses of the marine environment, to better predict the impacts of such use, to manage those impacts in a manner that ensures the long-term health[24] and sustainability of marine ecosystems, and to help restore ecosystems damaged from past and current activities or events.

Rationale

Marine ecosystems provide abundant products and services that not only enhance, but also are essential for, life on Earth, such as climate regulation, food and marine products, waste disposal and pollution control, energy sources, and recreation[25]. Marine ecosystems range from the Great Lakes and ice-capped polar expanses to warm tropical seas, from deep-ocean waters and productive continental shelves to coastal waters, including bays, estuaries, and wetlands. They interface with terrestrial ecosystems not only at shorelines, but also through watersheds and the atmosphere. Marine ecosystems are also subject to individual and cumulative impacts from an array of human activities (e.g., resource extraction, shoreline alteration, modified land use, increased flux of compounds, introduction of invasive species) and natural events and processes (e.g., hurricanes).

Much remains to be learned about the structure, function, and vulnerability of ecosystems, including factors controlling ecosystem stability and function; processes across the air-land-water interface, including the effects of human activities; linkages between ecosystem types (e.g., riverine and coastal, continental shelf and deep pelagic) and trophic levels; and the role of marine ecosystems in the ocean-Earth-atmosphere system that enables life in its myriad forms. Scientific understanding provides the foundation for effective management and governance that will help ensure the sustained vitality and diversity of marine ecosystems, as well as the social, economic, ecological, and human-health benefits society derives from them.

Research Priorities

Effective and adaptive ecosystem-based management will require a more complete understanding of the mechanisms governing ecosystems and an ability to accurately predict society's effects on them. Expanding understanding of ecosystem structure, function, complexity, and stability will require investments in exploration, inventory, and novel methods to investigate ecosystem components and their interactions. Such investigations will be complemented by research in other societal themes, all of which are linked to marine ecosystem health. This improved understanding and predictive capability will enable effective evaluation of the success of management efforts (e.g., MPAs).

Research Priority 14: Understand and predict the impact of natural and anthropogenic processes on ecosystems.

The complex relationships that determine ecosystem structure and function vary spatially (e.g., local, regional, basin-wide, global) and temporally (e.g., seasonal, annual, decadal, centennial), and incorporate various feedback effects. Shifts in ecosystem structure can be induced by climate-ecosystem interactions (e.g., impacts from El Niño/La Niña, increases in ocean temperature, ocean acidification), human activities (e.g., watershed activities, sediment/nutrient/contaminant flux, resource extraction), and productivity-driven or predation-driven trophic mechanisms (e.g., invasive species). Understanding these relationships requires incorporating new and existing knowledge and observations at appropriate temporal and spatial scales to explore the full range of physical, chemical, biological, and ecological mechanisms that determine observed ecosystem structure, function, and variation. Improved ecosystem forecasting requires: (1) comprehensive analyses of natural and anthropogenic changes in physical, biological, and chemical properties and their individual and cumulative impacts on productivity and overall ecosystem health; (2) assessment of dispersal mechanisms for marine organisms; (3) development of next-generation trophic dynamics models, spanning multiple trophic levels; and (4) process studies and model development to assess impact (loss) and recovery responses to natural and anthropogenic stressors.

Research Priority 15: Apply understanding of natural and anthropogenic processes to develop socioeconomic assessments and models to evaluate the impact of multiple human uses on ecosystems.

Understanding human impacts on marine ecosystems, whether positive (restoration) or negative (degradation), will require integrating traditional ocean science with socioeconomic science. To determine and predict society's total impact on marine ecosystems, social and economic factors (e.g., energy uses, coastal and watershed development, land use, water use, resource-use perception) that determine how society views and uses marine ecosystems must be assessed and modeled. Existing non-market values of ecosystem services and processes are often geographically and topically fragmented, rendering temporal and spatial analysis of non-market valuation difficult. Research efforts must include developing new methods to evaluate non-consumptive use of ecosystem services and characterizing the value society places on competing uses. To ensure sustainability of ecosystem goods and services, those methods must consider the rights of future generations and include discounting procedures for adjusting cost-benefit analyses over time.

Research Priority 16: Apply understanding of marine ecosystems to develop appropriate indicators and metrics for sustainable use and effective management.

A robust suite of indicators of ecosystem structure, function, productivity, and services must be evaluated and implemented at multiple scales (local, regional, basin-wide). These indicators will help assess factors that stress and degrade ecosystems (e.g., eutrophication and harmful algal blooms, loss of coastal wetlands, shoreline development, overuse of harvested species, invasive species, introduction and cycling of contaminants, changes in biodiversity, ecosystem productivity or resilience). Additionally, indicators and metrics are needed to help monitor the restoration and recovery of degraded ecosystems. Input from a range of scientific disciplines is needed to identify such indicators or develop them where existing indicators are insufficient or gaps are identified. Metrics and indicators must evolve based on new scientific understanding and management needs and goals. Such metrics and indicators, evaluated through integrated ecosystem assessments, will provide feedback for assessing management efficacy and a basis for incorporating new information and understanding to adapt and improve management practices.

Necessary Tools

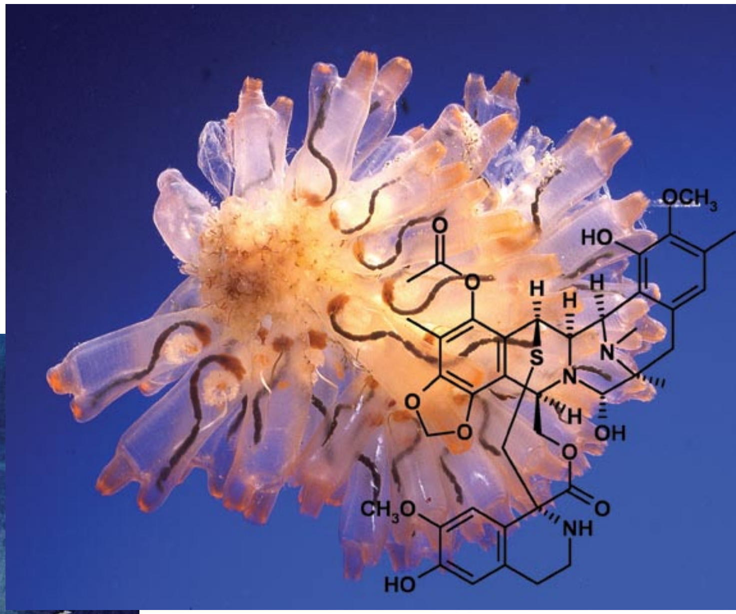
These ambitious but essential research priorities depend on the continued development and implementation of ocean-observing capabilities for assessing physical, chemical, and biological properties of marine ecosystems at appropriate temporal and spatial scales, as well as for assessing human impact on key ecosystem properties, such as productivity, diversity, and resilience. Effective observing capabilities must provide essential data on ecosystem types, ranging from terrestrial watersheds, to productive coastal and continental shelf regions, to the deep, pelagic realms. The information gathered will support essential ecosystem-related analyses and provide necessary input into effective, reliable ecosystem models. Collection of such data will require extensive infrastructure, including research vessels, automated buoys, and autonomous vehicles for short- and long-term sampling of water-column properties; satellite-based assessment of surface characteristics (e.g., temperature, biogeochemical properties, surface currents, wave heights); *in situ* observatories in the ocean, on the seafloor, and across the land-water interface; shore-based facilities for sample analysis, experimental manipulation, and observing-system maintenance; and a range of survey (e.g., mapping) capabilities. Improvements in information technology and infrastructure also will be essential to ensure that data assimilation, analysis, and modeling tools are available accommodate and enable the integration of ecosystem and socioeconomic data.

Ensuring an effective and adaptive ecosystem-based research and management approach requires an investment not only in technology and infrastructure, but also in the education systems that produce the scientists and managers needed to implement this approach. Research efforts also require a diverse workforce knowledgeable in natural aquatic and terrestrial sciences (e.g., biogeochemistry, taxonomy, systematics[26]) and social sciences (e.g., sociology, economics), as well as individuals trained in transforming data into information products for end users.

Theme 6: Enhancing Human Health

The ocean can be a source of health hazards. Understanding the causes of health hazards and how they can be mitigated or managed will lead to fewer illnesses from contaminated seafood, polluted waters, known and emerging disease-causing microbes, and harmful algal blooms (HABs). In the next decade, efforts to enhance human health will focus on the cause, prevention, and treatment of disease. The ocean also holds abundant resources that convey a variety of health benefits to humans. Exploration of new habitats, combined with emerging biochemical and biotechnical techniques, will promote discovery and development of bioproducts that promote human health.

Yondelis® (trabectedin, ET-743) was originally derived from the mangrove tunicate *Ecteinascidia turbinata*, which occurs throughout subtropical mangrove and sand-flat habitats in Florida, the Caribbean, and Mediterranean. It is now produced synthetically and is being developed by PharmaMar in partnership with Johnson & Johnson Pharmaceutical Research & Development (J&JPRD) for the treatment of soft-tissue sarcomas and ovarian cancer. *Photo credit: Harbor Branch Oceanographic Institution.*



Microsystis bloom, August 2003 as seen in Landsat 7 photo of western Lake Erie. *From Backer, L.C. and D.J. McGillicuddy. 2006.* Oceanography *19(2), Figure 8 by OhioView/T. Bridgeman*

Rationale

Waters from the open ocean, coasts, coastal watersheds, and Great Lakes present health risks to people through the consumption of contaminated seafood or drinking water (containing pathogens, toxins, or current or emerging contaminants); direct contact through recreation, work, and weather events; and indirect contact such as breathing salt air that may contain algal toxin aerosols. Illnesses due to the consumption of contaminated shellfish and finfish are estimated to affect hundreds to thousands of people per year[27]. However, these figures are uncertain due to major gaps that exist in illness reporting and epidemiological knowledge of seafood-caused[28] human illnesses[29]. Given the number and diversity of marine organisms and associated pathogens, the ocean should not be overlooked as a potential reservoir of pathogenic threats to humans[30]. Isolating the causes and impacts of these hazards will help protect human health and safeguard the quality of the seafood supply.

In addition to providing a wealth of known resources such as food, the ocean is full of potential human-health assets. In recent decades, scientists have discovered whole new ecological communities in the ocean with unique biochemical systems, such as those associated with thermal vents and hydrocarbon seeps. These communities, along with ones yet to be discovered, hold huge possibilities for development of products to improve human health and well-being. Prior discoveries that now have practical applications include pharmaceuticals (i.e., anti-cancer drugs), diagnostics (i.e., endotoxin detection), molecular probes (used in biochemical process/disease research), and nutrients (e.g., xanthophyll feed additives derived from algae)[31].

Research Priorities

The ocean community faces many challenges in addressing the relationship between the ocean and human health. Adequate process studies and assessments, monitoring, and data sharing and interpretation are needed to determine sources of human health risks, assess and predict risks to human health from those sources, and support the needs of a wide variety of end users. Expanded exploration and investigation of the ocean environment will contribute to our current understanding of the potential benefits from the ocean. These efforts also strongly interface with initiatives to improve ecosystem health and understand ecosystem processes, impacts of climate change, and effects of natural hazards.

Research Priority 17: Understand sources and processes contributing to ocean-related risks to human health.

Investigations into ocean-related risks should target ocean ecosystems and processes that impact human health. The introduction (e.g., runoff, atmospheric deposition), cycling (sediment, water column, atmospheric), and effect (chronic and acute) of current and emerging pathogens, toxins, and contaminants (e.g., mercury, flame retardants, endocrine disruptors, hydrocarbons) must be evaluated in coastal, ocean, and Great Lakes environments. Assessments of food webs can help determine the fate of these compounds (e.g., bioaccumulation, biotransformation, biomagnification), which can impact human health. Coastal and watershed processes and mechanisms that stimulate and sustain HABs must also be ascertained. Given current climate trends, the influence of climate change and variability on water-borne diseases (e.g., cholera) must be determined. Identifying, developing, and implementing new and improved sensors, rapid assays, models, and methods will enable assessment, monitoring and prediction of a variety of human health risks, such as HAB onset, extent, and duration; infectious disease potential (including microbes that can cross from animal to humans); and pollutant source and loading. These new sensors and methods will also provide crucial information related to the health of marine wildlife populations. The resulting improved understanding will enable development of mitigation strategies and technologies, such as stormwater-runoff and wastewater-discharge controls, and new approaches to minimize health-related impacts of hurricanes and other natural hazards.

Research Priority 18: Understand human health risks associated with the ocean and the potential benefits of ocean resources to human health.

While many ocean-based benefits and risks to human health are known, most are poorly understood and their direct health effects on humans are inadequately documented[32]. Benefits to humans associated with consumption of seafood (e.g., improved cardiovascular health, cognition) should be better characterized. Investigations should also quantify risks and impacts of exposure to health hazards (e.g., contaminants, pathogens, and toxins) via various pathways, including skin contact, respiration (e.g., inhalation of airborne materials), and consumption of food or water and determine the incidence and severity of human illnesses. Efforts to quantify risks and benefits require improving assessment methodologies and enhancing the accuracy and sophistication of epidemiological studies. Initial epidemiological studies focusing on risks should be directed towards those human populations expected to be most at risk (e.g., children, pregnant women, individuals with compromised respiratory or immune systems, people who spend a large amount of time on or in the ocean, coasts and Great Lakes—such as commercial, recreational, or subsistence fishers) and on diseases in ocean species that may serve as sentinels for new or ongoing threats. Ocean data and modeling should be integrated with assessments and epidemiologic studies to define exposures and focus risk assessments.

Research Priority 19: Understand how human use and valuation of ocean resources can be affected by ocean-borne human health threats and how human activities can influence these threats.

Coastal and Great Lakes environments are highly attractive places for recreation and they play major roles the nation's culture and economic vitality. However, the use and value of these environments and their resources may be significantly impacted by ocean-borne threats. These impacts include, but are not limited to, beach closures, constrained resource use (e.g., fishery and shellfish harvest area closures), and reduced marine operations and recreation due to contamination by pathogens, toxins, or pollutants, and other human-health threats (real and perceived). Human activities, such as coastal development, contribute to the onset and persistence of many of these human health threats. Understanding and predicting the relationship between social and economic drivers (e.g., shoreline development, tourism, recreational and subsistence fishing) and human-health threats will require integrating socioeconomic data and investigations with ecosystem-based studies of health threats at appropriate temporal and spatial scales. The integration of information from natural and social sciences will, in turn, help support management and mitigation efforts.

Research Priority 20: Apply understanding of ocean ecosystems and biodiversity to develop products and biological models to enhance human well-being.

The intricacies and biodiversity of ocean ecosystems provide unparalleled opportunities for discovery and development of useful materials. Collaborative research efforts incorporating multiple disciplines (e.g., evolution, ecology, genomics, pharmacology) should focus on expanded exploration (conducted with care to prevent transfer or introduction of wildlife diseases or invasive species), assessment (e.g., genomics, advanced non-culture based methods), and development (e.g., biosynthesis) of ocean bioproducts (e.g., pharmaceuticals, nutrients, diagnostic tools, reagents, enzymes). Research efforts should also include developing the capability to use marine species as mechanistic models for the study of diseases, toxicology, and biochemical processes relevant to human health; and identifying and using appropriate sentinel species (e.g., aquatic, avian) and habitats that may serve as early-warning systems of potential ocean risks to humans.

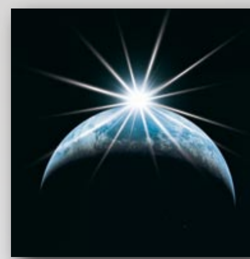
Necessary Tools

A system is needed to record illness data due to pathogens, biotoxins, and chemical pollutants. Integral to this system is expanded environmental monitoring and infrastructure. Such a system would require collection of human and animal health data and relevant environmental data (via remote, moored, and mobile platforms and sensors as part of an integrated ocean-observing system), coupled with new data integration and interpretation capabilities, and rapid data-communication plans. Once in place, the system could serve to monitor and predict ocean conditions that place people and other animals at risk or that may be favorable to human health.

Sensors capable of detecting biological and chemical parameters, such as microbial species and densities, and toxin and contaminant identifications and concentrations must be enhanced or developed. Remote sensing of ecological changes and real-time, high-frequency (temporal and spatial), *in situ* monitoring combined with modeling efforts (statistical-empirical and mechanistic) are necessary to inform understanding of ecosystems and to track and predict outbreaks and other impacts. Designing advanced sensors for hostile and extreme environments will enable more extensive ocean exploration. Developing, enhancing, and applying new methods and tools at shore-based marine laboratories and other facilities with specialized instrumentation (e.g., for large-scale gene sequencing) and computational resources in areas such as genomics, proteomics, and bioinformatics will expand surveying and screening capabilities. Improved coordination of federal and state data systems is needed for toxic algal-bloom monitoring, pathogen-source tracking, marine-disease surveillance, and medical-illness reporting, and in the design and development of a national database of monitoring and screening methodologies.

Many of the research efforts require interaction between oceanography and other disciplines, such as biomedicine and public health, to provide a broader understanding of the issues and to communicate the results of this research to support effective decision-making.

Opportunities for Progress



Developing the Tools

To address key ocean-related societal issues and to apply existing understanding to support meaningful decision-making requires development and implementation of a broad infrastructure. Each societal theme outlines the tools needed to address the respective research priorities, such as vessel time and new ship-based technologies (Stewardship of Natural and Cultural Ocean Resources, Improving Ecosystem Health), shore-based facilities with specialized instrumentation (Enhancing Human Health), and reactive deployment capabilities (Increasing Resilience to Natural Hazards), all of which are critical to pursing the research priorities. Several key infrastructure needs were common across many themes and are described below.

Observing Systems

The need to acquire, manipulate, analyze, and deliver requisite information about the ocean calls for development of an integrated ocean-observing system that includes coupled observational and research components. This system will consist of existing capabilities (e.g., established *in situ* networks, current and planned satellite missions) that will be continually integrated with future systems (e.g., seafloor networks, regional observing systems). Covering a diverse suite of spatial (coastal watersheds to polar seas) and temporal (microseconds to decades) regimes, an integrated ocean-observing system will provide data (in real time or near real time) to address a broad spectrum of societal

and ecological issues, including human-dimension processes; build the foundation for advancing basic understanding of open ocean, coastal, coastal watershed, and Great Lakes processes; and revolutionize scientific and public access to the ocean. An integrated system represents an ambitious effort of the national and global ocean community to establish and maintain a robust, adaptive, continuous presence in the ocean and provide critical information and models to users and stakeholders. Given the interconnected nature of land-sea-air systems, an integrated ocean-observing system should be capable of interfacing with current and future terrestrial, aquatic, and atmospheric observing systems and be closely coordinated with the Global Ocean Observing System, as part of the Global Earth Observing System of Systems (GEOSS)[33]. Several key steps must be taken to fully implement the system:

- Fully integrate existing (e.g., buoy networks) and future (e.g., surface-water-quality monitoring networks) components of a national observing system ("national backbone") to provide nationwide coverage of the most commonly required ocean parameters.
- Expand regional and local coastal observing-system capabilities (fixed and mobile) to provide greater density and diversity of observations on a regional basis, and address region-specific observational needs, such as watershed-specific monitoring and land-water fluxes.
- Maintain continuity of existing satellite missions and incorporate new remote-sensing capabilities into future missions. Integral to this effort is the need for continued sensor development, validation, and calibration that will ensure delivery of functional data to users.
- Incorporate new and existing biological, chemical, physical, and geological measurements into the observing system, and expand sensor development for biological, chemical, and physical parameters.
- Implement data-management and communications plans that will modernize existing data systems. Integrate current and future systems by promoting interoperability among system components; developing metadata standards; integrating new components; and enabling data discovery, availability, use, and archiving of the data streams collected by the observing system and other observing assets (e.g., vessels).
- Integrate the data needs for decision-support tools into the development of observational and information systems and models.

Models

Combining existing data sets with scientific and social theory and modeling will enhance understanding and address user needs by providing a window on past conditions, permitting an assessment of present conditions, and enabling predictions of future conditions. Models may be developed for several reasons, including *exploring* the relationships among physical, chemical, biological, and socioeconomic variables; *hindcasting* previous conditions in an area; and *forecasting* the impacts of environmental change or management practices.

Models can comprise a certain configuration, including parameters, domain, and boundary conditions. The term model can also be used to describe a modeling system, which incorporates an array of algorithms (a set of sequenced, computational instructions) from which the most appropriate combination can be selected for a particular application. The discussion of models throughout the societal themes incorporates both model configurations as well as modeling systems.

Key elements to enable modeling efforts nationwide:

- Expand translation of data and insight derived from ocean research and observations to improve representation of this information in models.
- Develop new application-specific model configurations where necessary.
- Consolidate existing modeling capabilities into a flexible and comprehensive unified ocean-modeling software environment, building on the diverse existing community and developmental ocean models.
- Improve model analysis and capabilities through model diagnostics and intercomparison activities.
- Conduct systematic best-practice studies to develop guidance in the selection of optimal algorithms and techniques for particular modeling applications.
- Expand development of high-resolution, global ocean model configurations for use in real-time, short-term forecasts out to days or months, reanalysis of historical ocean state, and multi-century climate forecasts.
- Expand current computational capacity to assimilate increasing amounts of data provided by ocean-observing assets and to support and process model advancements incorporating increased process and mechanistic understanding.

To ensure the effective use of model output, developers and users must address several issues, including how the temporal and spatial scales of the input data compare to the outputs and products, how uncertainty in data sets and model calculations is propagated, and how the models are intended to be and are actually used.

Making a Difference

Information To Support Decision-Making

Scientific results must be actively translated into readily understandable information and made available to the public, and their trustees and elected representatives. Information from managers and decision-makers will, in turn, help develop and inform research efforts.

Develop mechanisms to further integrate research results into adaptive management efforts.

Effective resource management must include mechanisms to design, evaluate, and modify management approaches. Science-based management decisions require a close coupling of problem formulation and data collection. A two-way interface connecting research results and management efforts will support more rigorous adaptive management, where management efforts are designed and can be modified based on empirical evidence of system response. This interface between researchers and decision-makers, enabled through extension programs and technical training, will allow managers to acquire the information they need, and researchers to help focus research to priority areas identified by resource managers.

Establish dedicated mechanisms to translate research results into readily used products.

To enhance communication among sectors (e.g., researchers and resource managers) and enable translation of results into readily used information products, communication strategies must be investigated, developed, and enacted. Part of these communication efforts may include the development of professional communicators to assist researchers and end users in developing more accessible, derivative products. These professional communicators would be cognizant of both scientific objectives and management goals. Communicators can also help groups exchange information, including research needs and research results, and enhance communication among disparate sectors.

Foster mechanisms to transition developing technologies into operational capabilities.

Many of the research priorities outlined in this document require new sensors, platforms, data-management technologies, and models. However, there is often a gap between the development of these capabilities and their use as robust components of integrated systems. Fostering communication among agencies, researchers, engineers, and end users will support efforts to overcome technical barriers and promote effective development, implementation, and use of these technologies.

Establishing An Ocean-Literate Nation

The goal of ocean education is a nation whose citizens are good stewards of the ocean and who possess the knowledge to make informed decisions about their interactions with it. This goal can only be attained through improved education efforts for the entire spectrum of ages ("K–gray") through formal and informal education—to ensure ocean literacy for the general public, development of a well-trained workforce, and more effective communication.

Ocean research provides the information needed to develop education, communication, and management materials that are based on sound science. Ocean-research activities also provide a training ground for a range of ocean professionals, an aspect of the research enterprise that is particularly important as ocean science incorporates other fields, such as medicine and social sciences. Efforts to enhance ocean literacy will support and, in turn, be supported by efforts to promote fundamental math and science skills. Coordinated and sustained education and training efforts for diverse groups, from government agencies and the academic community, to school systems and scientific societies, will promote a knowledgeable, ocean-literate public and a larger and well-prepared workforce. These efforts will help retain U.S leadership in science and technology.

Expand and sustain formal and informal education efforts

Currently, ocean science is rarely included in formal education settings. Assessing current ocean-based curricula and then developing well-focused, ocean-related materials will help incorporate ocean science into K–12 curricula, in coordination with ongoing national science education efforts. Ocean science is an ideal mechanism to convey fundamental scientific concepts and mathematical skills. Providing professional-development opportunities for teachers ("educating the educators") and expanding and acknowledging the role of scientists, managers, and policy-makers in education and outreach efforts are additional key steps in expanding ocean science in formal education settings.

Incorporation of education goals will add value to research efforts. Integrating ocean-observing data and information product into K–12 classrooms will help realize the full potential of the observing systems and provide real-world application to the learning environment. Strategies for using these data need to be coordinated at a national level.

Aquaria, museums, marine laboratories, science centers, zoos, and other informal-education centers welcome over 142 million visitors a year and play a major role in educating the public about the ocean[34]. Media outlets, such as newscasts, television specials, movies, magazines, and online portals, provide necessary information, such as hazard warnings, and provide a window into the world of ocean-science exploration and discovery. Citizen science initiatives can also serve to engage citizens with the ocean while promoting ocean research and monitoring efforts. Expanding and supporting these forums for lifelong learning will enable the transfer of understanding about the ocean from the research community to the general public.

Advancements in formal and informal education must be accompanied by efforts to address and capitalize on differences in culture, geography, language, and values to reach a diverse audience. These efforts should include strategies to recruit and retain students from all population segments.

Expand intellectual capacity

The diversity of technical and research requirements presented in this document illustrates the need for a well-trained workforce, including individuals with disciplinary (e.g., biology, chemistry, geology, physics), interdisciplinary (e.g., biogeochemistry, aquatic, and terrestrial sciences), and inter-community (i.e., connecting oceanography, biomedicine, engineering, economics, information technology, public health, community planning) training. This need is particularly evident as ocean science expands from having single-discipline foci to addressing topics that transcend natural sciences and incorporate social and economic sciences. The workforce necessary to use the research results outlined in this document must include individuals who are well versed in scientific discovery and understanding, and who possess the means to effectively communicate research results to inform management decisions and policy development. Developing this workforce requires new models by which students are trained and evaluated that recognize the value of interdisciplinary work. Individuals trained in research must also be educated in policy, regulation, and resource management to better understand and address user needs, where appropriate.

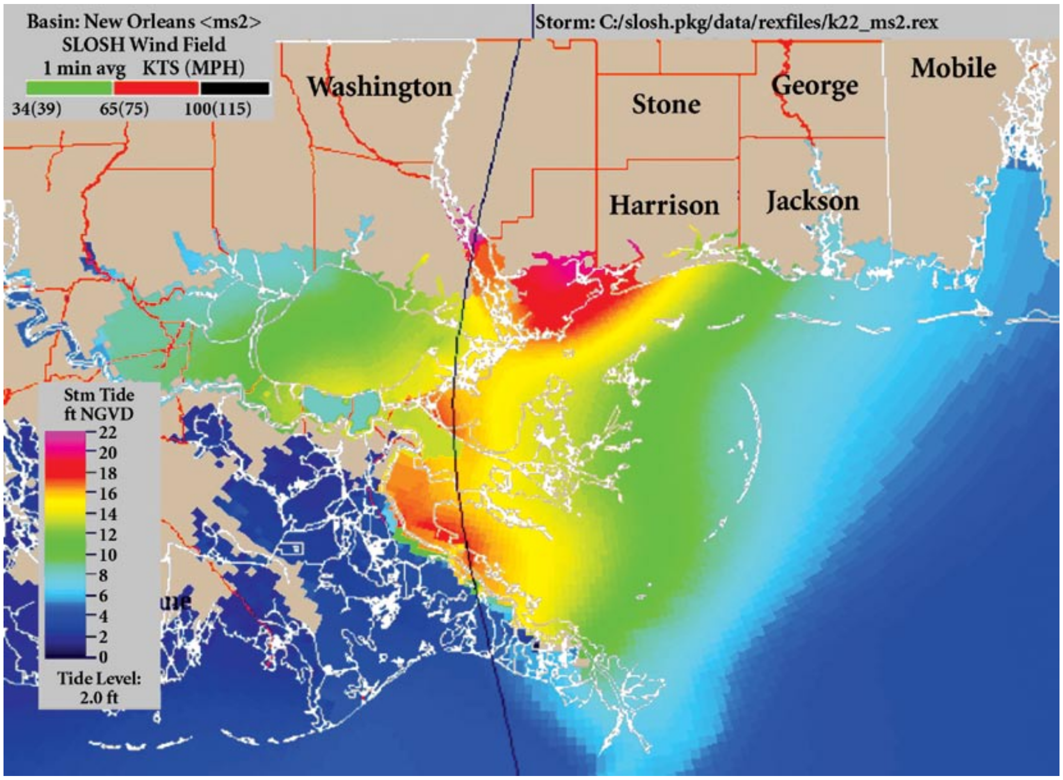
Near-Term Priorities

The Joint Subcommittee on Ocean Science and Technology (JSOST) developed four near-term (2–5 years) priorities, each with equal weight, to focus initial research efforts. However, these efforts do not preclude other activities towards all 20, longer-term (7–10 years) research priorities. These near-term priorities, which reflect multiple aspects of the national research priorities and the critical tools needed to address them, were selected from a larger suite of efforts using the criteria outlined in Identifying Ocean Priorities, with an added focus on impact (i.e., the value of the work), urgency (i.e., the need for a concentrated effort over the next two to five years), and partnerships (i.e., the effort will maximize collaborations among agencies and external partnerships). The primary societal themes from which the near-term priorities were developed are highlighted in the individual discussions.

1 Forecasting the Response of Coastal Ecosystems to Persistent Forcing[35] and Extreme Events

Coastal ecosystems are subject to a variety of forcings, ranging from extreme events (Increasing Resilience to Natural Hazards), to human activities (Improving Ecosystem Health), to changing ocean conditions (The Ocean's Role in Climate). Understanding the response of natural and constructed landscapes and ecosystems (e.g., algal blooms, hypoxia, coral-reef bleaching, decline in sea ice) to these forcings; forecasting the frequency, intensity, and impact of those forcings; and providing tools to develop policy and management responses are integral to constructing more resilient structures and communities, and protecting the natural environment. Research and observations will focus on establishing the basis for both short-term forecasts and long-term, probabilistic assessments of coastal vulnerability to extreme events, persistent natural processes, and human influences across the coastal zone. This effort will enhance regional observing systems and models, integrate substantial existing observations, and incorporate new observations to address critical regional data gaps. Data and information products will be made widely available to diverse end users through a national ocean-observing capability. Results from this effort will inform hazard mitigation and response plans, provide forecasting data to support navigation safety, and assist regional resource managers and public health officials in sustaining ecosystem and public health, and promoting hazard resilience.

Observations of physical characteristics and processes, including material inputs from adjacent watersheds and contributing airsheds, ocean influences on hurricane intensification, and characterization of submerged and coastal landscapes, will be integrated to support data-assimilative modeling of, for example, water quality, nutrient, sediment, and contaminant transport; waves and water levels; and the coastal response to hurricane processes. Biological observations, including new DNA-based techniques, will enable development of coupled physical and biological models of ecosystem-level response to various stressors. Coupled research, observations, and model development might focus on identification, quantification, and transport of pathogenic microbes and various species of harmful algae, and lead to robust, timely forecasts of human-health threats and natural-resource impacts. Additionally, linking environmental-quality data with public-health surveillance activities will support modeling and prediction of the geographic expansion of potential health risks from hurricanes and specific waterborne vectors, toxins, and pathogens.

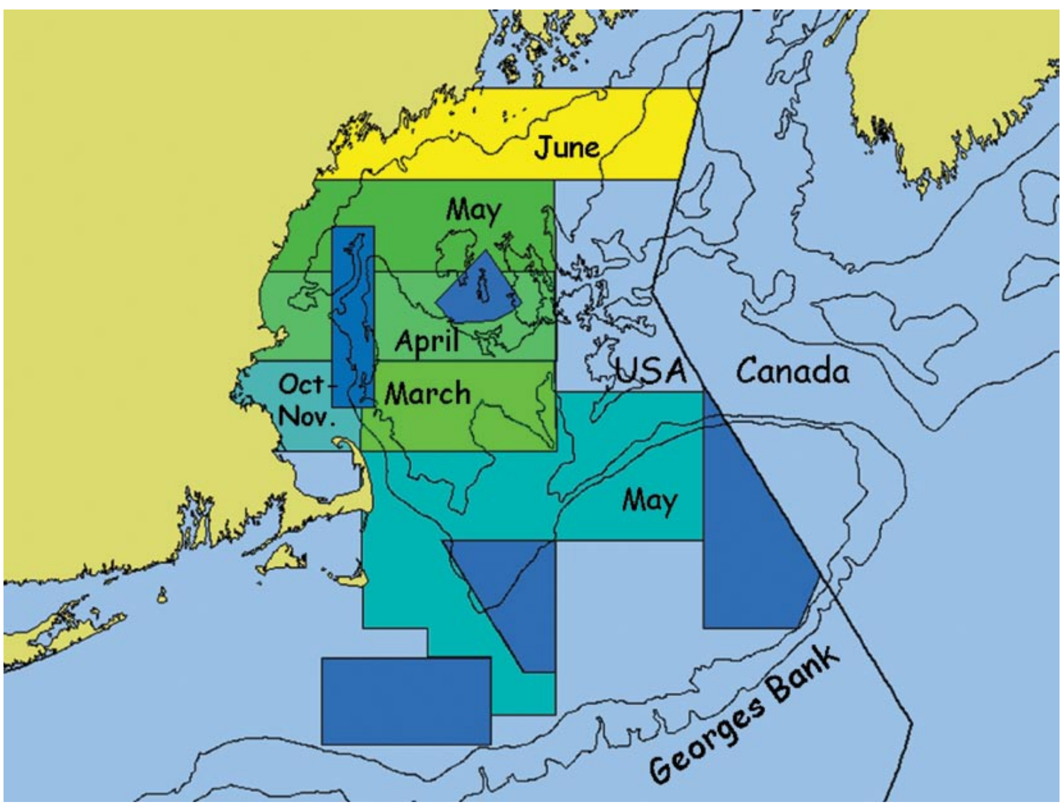


Storm surge data posted by the National Hurricane Center at 9:20 AM CDT 8/28/05 provided critical data on the potential impacts of Hurricane Katrina. *Graphic credit: NOAA*

This effort will build upon extensive existing data sets, surveillance, observational, and modeling capabilities; promote the transition of models from research tools to operational applications; and support the establishment and linkage of regional and national ocean-water-quality data networks. Decision-support models will inform prevention strategies, rescue and recovery operations, spill tracking, safe maritime navigation, water-quality forecasting, and resource assessment and management, taking into account the vulnerability of ecosystems as well as their capacity for mitigating harmful impacts. Focus areas for implementation will be identified to build upon existing assets where integration and enhancement provide the greatest opportunity to impact public safety and public, economic, and environmental health.

2 Comparative Analysis of Marine Ecosystem Organization

Forecasting marine-ecosystem responses to management strategies requires an understanding of the complex dynamics that control and regulate ecosystem processes (Improving Ecosystem Health, Stewardship of Natural and Cultural Ocean Resources). Management of marine ecosystems can be improved by elucidating the underlying dynamics of these systems at a variety of scales. This effort will provide a greater basic understanding of ecosystem processes and practical tools for evaluating the effectiveness of local and regional adaptive ecosystem-based management efforts.



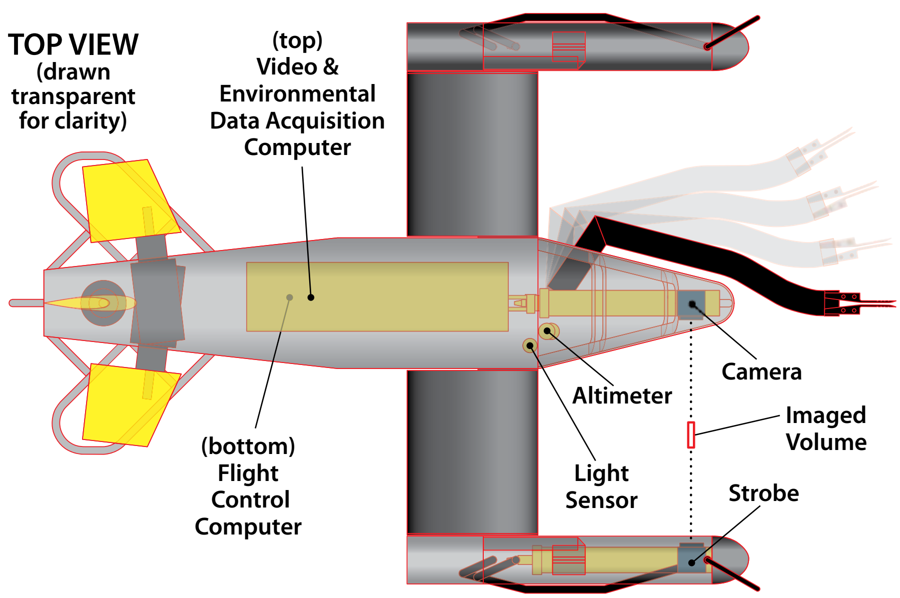
Marine Protected Areas (MPAs) off the Northeast United States. Dark blue areas are closed to certain fishing techniques year-round, while other regions are closed in certain months. *Graphic credit: NOAA*

Ecosystem-based approaches emphasize interactions among components and the impacts that various human activities have on productivity and organization. Forecasting these impacts requires understanding complex dynamics controlling: (1) productivity of various trophic levels, (2) predator-prey interactions, (3) connectedness of subpopulations, (4) impacts of natural climate variation, and (5) anthropogenic pressures. Because classical controlled experimentation provides limited information on the complex dynamics of marine ecosystems, two types of analyses will be undertaken. The first approach will construct and apply various classes of energy-budget and dynamic models to managed marine ecosystems to enable greater understanding of the impacts of human activities by contrasting biomass changes according to trophic level. The second approach will compare systems where marine managed areas have been enacted to conserve species and ecosystems[36]. Such comparisons will include before and after area designation contrasts where sufficient data are available, and inside versus outside comparisons for established managed ecosystems. Mapping efforts will include ecosystem-scale characterization, design of interpretive products, and provision of tools to assimilate and disseminate geospatial information in support of research, observations, modeling, forecasting and management decision support.

Candidate ecosystem types for inclusion in this study may include the sub-Arctic, continental shelves, coral reefs, and estuaries. Analyses of these ecosystems will focus on how feedbacks influence ecosystem productivity, biodiversity, and conservation of managed species through comparisons using consistent modeling frameworks. Evaluation of the effects of management efforts will involve assimilation and synthesis of existing biological information by trophic level, linkages to higher levels, and impacts on human-use patterns (e.g., displacement of human activities from marine protected areas and their socioeconomic effects). These efforts will help ensure that effective ecosystem-based management strategies are based on sound scientific understanding.

3 Sensors for Marine Ecosystems

Advances in ocean sciences have been made possible by technological innovation. The development of new sensor capabilities, integral to many of the research priorities, will help realize the full potential of *in situ* observing networks and satellite-based observations (Developing the Tools) and enhance understanding of marine ecosystems (Improving Ecosystem Health, Enhancing Human Health). Currently, significant limitations exist in observational capabilities and associated methodologies. Advancements in sensor capabilities can revolutionize understanding of the ocean environment by providing information at temporal and spatial scales not currently available.



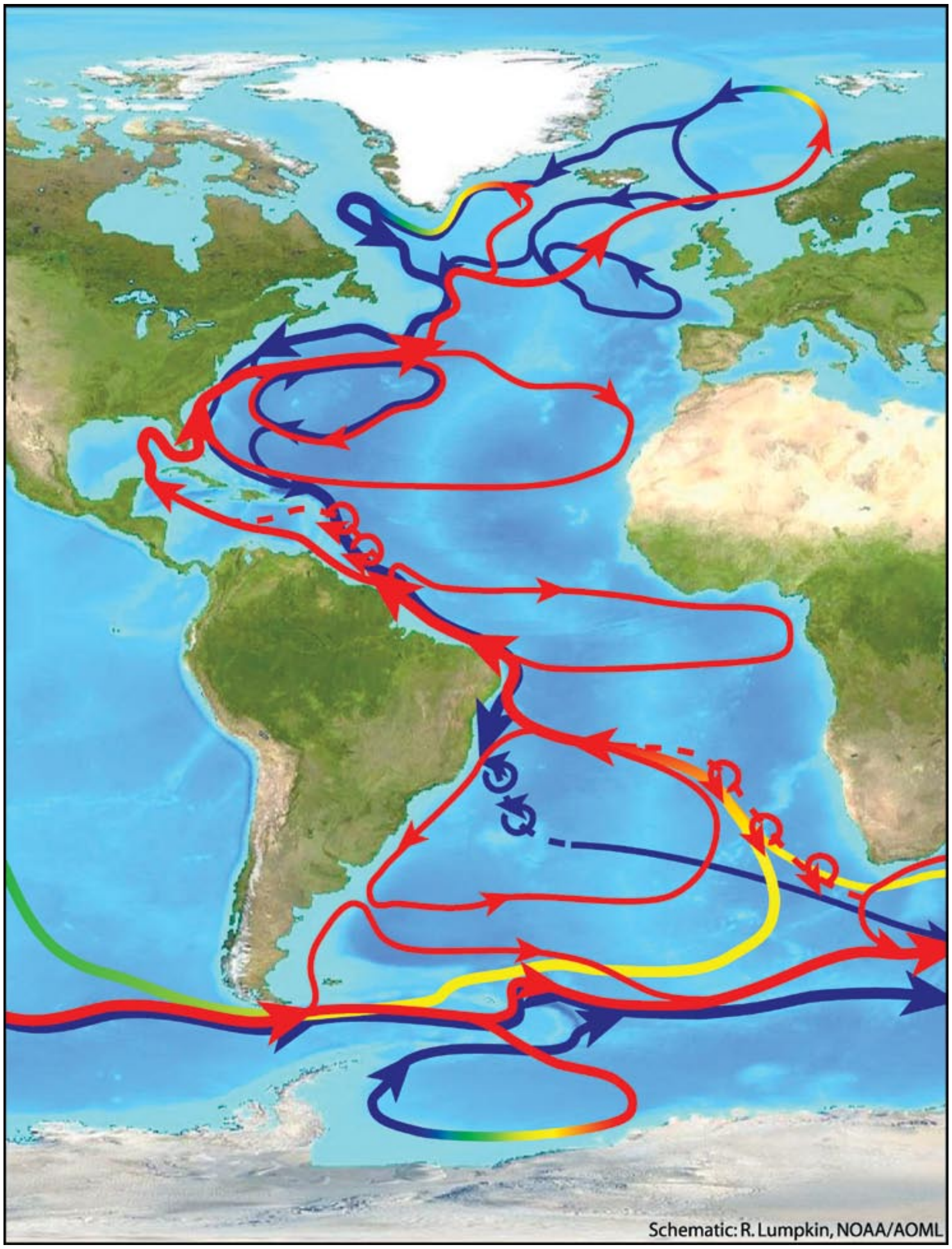
Video plankton recorders (VPR) and other advanced biosensors can be used to provide rapid and synoptic data on biological phenomena (such as copepod abundance on Georges Bank). *Graphic credit: Jayne Doucette, Woods Hole Oceanographic Institution*

Immediate improvements can be made to *in situ* instrumentation in eco-genomics, to interdisciplinary ocean observing, and to sensors in support of satellite-derived ocean color (used to estimate biological [phytoplankton] and biogeochemical [carbon] materials in surface waters) and new biological and biogeochemical observations. Creation of a common library of genetic "barcodes" is a critical step in the development of fast, economical genetic screening procedures to identify marine organisms. Such procedures will help reveal basic ocean processes controlling biodiversity and productivity, such as the distribution and abundance of harmful algae and pathogens. Advancing novel capabilities and moving high-impact/high-utility sensors from research to broad operational use will allow for physical sensors capable of providing a better understanding of ocean transport and fluid velocity, and chemical sensors that can reliably detect toxins and ecologically important nutrients. Enhancing in-water instrumentation used in ground-truth exercises will improve the quality and usefulness of ocean-color data provided by satellites, and will aid in the development of new space-based, ocean biological and biogeochemical measurements. Improving ground-truth and *in situ* observations will significantly advance understanding of—and ability to model—ocean systems (ecology, biology, carbon) and their role in the Earth system, as well as the potential impact of human activities. Parallel advances in power-supply technologies and data transfer must also occur to ensure *in situ* sensor operation in a variety of environments and within a variety of networks. Advancing sensor capabilities will enable new, multiscale observations that provide information needed to better define marine resource management options, help understand processes that influence ecosystem health, serve as the basis for forecasting ocean-related risks to human health and safety, and shed light on the impact of climate variability and change on the ocean, marine life, and humans. Expanding sensor capabilities will build on existing mechanisms of support (e.g., agency programmatic priorities) and coordination (e.g., public-private partnerships), and development efforts (e.g., laboratory-based prototypes, expanded capability of existing satellite sensors).

4 Assessing Meridional Overturning Circulation Variability: Implications for Rapid Climate Change

The ocean plays a critical role in global climate. Thus, incorporating ocean observations and understanding into an integrated, Earth-system-analysis capability is needed to assess the current state of the climate system. Specifically, the Atlantic Ocean MOC, an element of the global-scale ocean circulation responsible for long-term climate variations, has also been identified as a key process related to rapid or even abrupt climate change (i.e., changes over a few years to a few decades) (The Ocean's Role in Climate). Rapid changes the MOC could have a profound effect on European and global weather patterns and ecosystems in the Atlantic Ocean.

Assessing the potential for future abrupt climate changes and developing the capability to predict their occurrence will require a national program that incorporates: (1) ocean observations, including *in situ* instruments (e.g., currents, temperature, carbon), satellites (e.g., sea surface height, surface vector winds), and ocean data computational and assimilation capabilities to provide routine, basin-scale analyses; (2) now-casting (an assessment of current conditions); (3) model development for decadal forecasting; (4) past climate-change reconstructions; and (5) climate-impact assessments. Ongoing national and international observing efforts and process studies aimed at improving climate and ocean general circulation models provide the foundation upon which to expand the understanding, observation, and prediction of the MOC and its impacts. New research on the MOC will build on the legacy of seasonal-to-interannual climate prediction systems developed since the 1980s based on Pacific and Atlantic tropical ocean variability. Establishing the basis for a long-term monitoring system for the MOC over the next two to five years will provide the observational data needed to challenge and improve climate models, and to more accurately establish the true variability of the MOC and its effects.



Pathways of the overturning circulation in the Atlantic Ocean that represent the large-scale conversion of surface waters (red arrows) to deep waters (blue arrows) that have global impacts. The Atlantic overturning circulation has many complex and interacting parts (e.g. rings, interbasin exchanges), but the most important aspect is the large heat it carries and its apparent sensitivity to the hydrological cycle and climate change. *Graphic credit: NOAA*

Implementation Strategy

Addressing the national ocean research priorities requires a nationwide effort. The involvement of end users of scientific information, including resource managers, public policy-makers, and individual citizens, will enhance the impact and value of research efforts. Given the significant investment state and local entities make in collecting and disseminating environmental data and supporting research, and the emerging role of private foundations in supporting ocean science, federal efforts represent a key, but not exclusive, element of the national research effort. A well-planned and robust federal effort will provide leadership, focused initiatives, and resources against which non-federal efforts can be better leveraged.

The implementation strategy described in this section is a set of operational principles and conceptual guidelines developed by the federal agencies (the JSOST) to address the national ocean research priorities. This section lays out the characteristics of implementation, the roles of various sectors, mechanisms for collaboration, the need for an infrastructure assessment, mechanisms for research translation, strategies for assessment and evaluation, and mechanisms for budget and plan updates. No one group or sector, including the federal agencies, is expected to address the priorities (near- and long-term) alone; thus, the efforts will reflect differing levels of investment from different sectors, depending on agency missions and sector interests and needs.

This section provides direction to ensure the ocean research priorities are successfully addressed; as such, it outlines an implementation strategy, not a detailed implementation plan. This section does not stipulate specific federal-agency actions or budgets, provide timelines for activities, or mandate how other sectors should respond to the research priorities independent of federal collaboration. Those activities—by virtue of their dynamic nature—are best defined in specific program and project plans. This strategy also leaves open the possibility that dialogue with non-federal partners will play a role in shaping detailed implementation plans intended to address specific research priorities. Applying this implementation strategy will lay the foundation for the multi-tier and multi-sector collaboration that is needed to ensure the nation's ability to make progress toward achieving the vision articulated by the USCOP and the Ocean Action Plan (OAP).

Implementation Characteristics

To successfully address both near- and long-term ocean research priorities, several implementation aspects must be considered.

Use of Existing Mechanisms

Many of the mechanisms required to address effectively the ocean research priorities currently exist (see Mechanisms for Collaboration). Capitalizing on appropriate existing mechanisms will streamline implementation by reducing redundant organizing efforts, helping develop and maintain collaboration among diverse parties, and helping ensure that the majority of available resources are dedicated to addressing the research priorities and realizing research results.

Partnerships

Partnerships among local, state, tribal, regional, federal, and international bodies, as well as academic institutions, nongovernmental organizations, and industry, are required to successfully develop, enhance, and expand current and future research projects in ocean science and technology. These partnerships will enable leveraging of limited resources across sectors, build user capacity, and promote connectivity among diverse groups and regions.

Merit-Based Peer Review

Independent peer review promotes rigorous, objective, and equal treatment of all proposals for addressing the ocean research priorities. Although this process may not apply with the same weight to all scientific pursuits, such as those in mission-oriented or operational agencies, the merit-based peer-review process enables investments in projects that couple the best ideas and the most capable members of the community.

Sustained Efforts Versus New Development

New initiatives and assets may be required to address gaps in knowledge or to take advantage of significant technological advances. However, many existing programs and infrastructure also address the research priorities. An appropriate balance of sustained existing efforts and new developments must be maintained for research efforts and the infrastructure that supports them.

National Priorities, Scaled Implementation

The development of ocean research priorities has focused a national effort on pursuing critical areas of ocean research necessary for the health and welfare of the nation. Successful efforts to address these priorities must account for differences in scales of the research efforts and research needs.

National implementation

Addressing certain research priorities requires national and/or federal effort. Many mechanisms to pursue this type of priority currently exist in the federal system and can be enhanced through the expanded agency collaboration under the Committee on Ocean Policy (COP) governance (see Mechanisms for Collaboration).

Regional, State, Tribal, and Local implementation

The national priorities outlined in this document need to be addressed at global to local scales and tailored to address differences among geographic regions, as well as different ocean uses, interactions, and phenomena within these areas.

Roles

The success of the effort to address the priorities described in this document requires the effective participation of not only federal agencies, but of numerous organizations and entities that exist in the United States and around the world.

Federal Agencies

Recognizing that no one group can fully address the ocean research priorities on its own, the role of the federal agencies is to provide the foundation of coordination, support, and resources to make progress on the priorities, consistent with the respective agency missions, and provide the impetus for collaboration among all sectors.

Local, Tribal, State, Regional Governance

Participation of governance entities at local, tribal, state, and regional levels will help ensure that efforts to address the national ocean research priorities are tailored to the needs of specific areas or groups, as appropriate. This focus can include the establishment of partnerships to address watershed or coastal issues affecting multiple states, such as accurate storm-surge and coastal-inundation forecasts. These governance entities also enable the effective use of results from nationally coordinated research efforts, such as hazards observations (e.g., hurricanes, tsunamis), by state and local agencies to advise the public and help mitigate impacts.

International Entities

International entities coordinate and implement global ocean research, management, and policy among the United States, other nations, and international groups. International entities also play a role in collaborating with the United States on all matters of regional oceanography (e.g., issues that cross national borders) and can influence research on natural hazards, ecological and human health, and fundamental processes affecting the Earth system.

Research Institutions

Research institutions provide a venue for scientific initiatives and collaborations among disciplines and sectors. These institutions can help enable close collaboration between researchers and stakeholders to better incorporate stakeholder issues into the research planning process, identify and coordinate synergistic research opportunities (e.g., shared data) among ongoing efforts, and identify and disseminate research findings to appropriate user groups.

Educational Institutions

Educational institutions communicate research results to the public and provide a foundation for informed discussion about society's interaction with the ocean. Educational institutions, ranging from the public and private K–16 educational providers, to universities, to informal venues such as aquaria, also provide a foundation for educating future researchers, managers, decision-makers, and leaders to expand understanding of the marine environment and to ensure the safe, effective, and sustainable future use of ocean, coastal, and Great Lakes resources.

Private Sector

The private sector provides expertise, resources, products, and services; uses research results in establishing economic development opportunities; and facilitates the development of research infrastructure. Developing research strategies in conjunction with the private sector will help ensure that these strategies leverage private-sector expertise, capability, and resources.

Nongovernmental Organizations

Nongovernmental organizations, such as advocacy groups and philanthropic organizations, are critical links among communities, whether representing and communicating needs, distributing resources, acting as conduits for research to enhance ocean literacy, or serving as stewards for the ocean ecosystem. Engagement of these organizations in developing plans to address high-priority ocean research is essential to ensure that diverse sectors have the opportunity to communicate and engage with each other.

Mechanisms for Collaboration

Among Federal Agencies

Collaboration and coordination among federal agencies was expanded with the establishment of the new governance structure under the COP (Figure 2). This new structure, comprised of representatives from the 25 federal agencies with interests or activities in the ocean, includes several subgroups that allow the federal agencies to coordinate efforts on issues such as science and technology (JSOST), resource management (Subcommittee on Integrated Management of Ocean Resources [SIMOR]), and international ocean issues (Ocean Sub-Policy Coordinating Committee [Oceans Sub-PCC]). Efforts within these groups are further defined along topical areas, including ocean education, partnerships, and observations. Other ocean-related interagency collaborations focus on topical or geographic areas (e.g., Committee on the Marine Transportation System, U.S. Coral Reef Task Force, Great Lakes Interagency Task Force) and can be accessed to facilitate efforts to address the ocean research priorities. The JSOST and SIMOR, under the integrating auspices of the Interagency Committee on Ocean Science and Resource Management Integration (ICOSRMI), are leading the effort to coordinate federal-agency activities. These activities will include coordinating with other federal initiatives (e.g., U.S. CCSP, U.S. Group on Earth Observations), expanding interaction with other sectors, promoting collaborations among sectors, and advancing connections with regional initiatives.

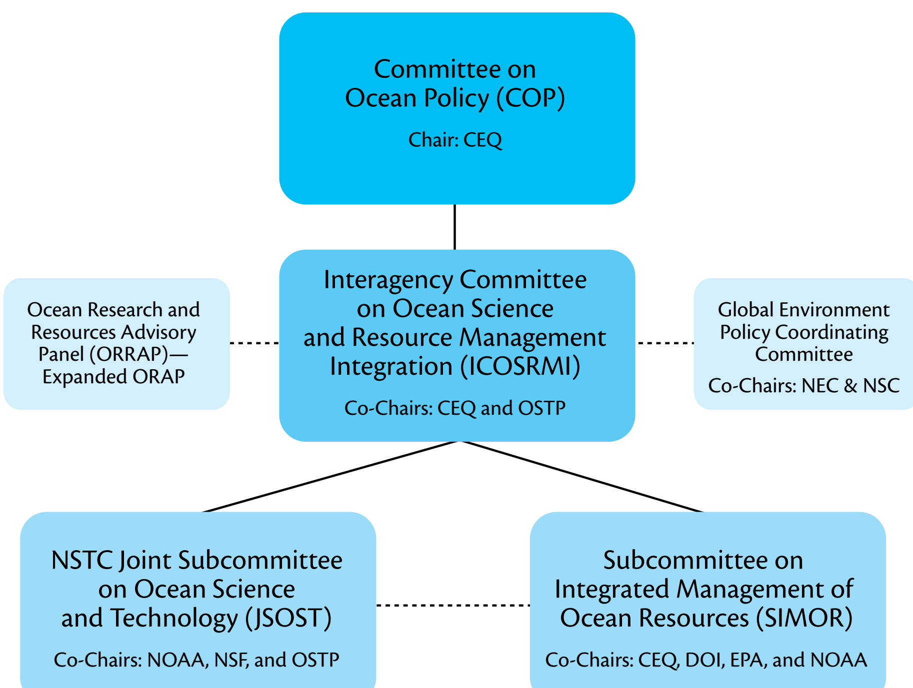


Figure 2. COP governance structure.

Within Regions

Mechanisms for collaboration within geographic regions exist on the federal scale as well as on the regional, state, and local scale. These mechanisms include forums for interaction between federal agency representatives and state officials and resource managers (e.g., SIMOR Federal-State Science and Management Integration Task Team [FSSMITT], Coastal States Organization) on issues that have regional, state, or local relevance, such as the ocean research priorities.

Key mechanisms for collaboration will be derived from existing regional, state, tribal, and local entities, and where needed, new mechanisms may be established to address regional ocean and coastal issues. It is critical that collaboration mechanisms at all levels of government remain flexible enough to address specific needs at the appropriate scale. For example, regional consortia have been used to define a set of regional challenges, set regional research priorities based on regional needs and national research priorities, and develop and enact regional research implementation plans. Although no single regional structure can be applied to all cases, several existing or emerging organizations demonstrate key aspects to consider. The Sea Grant program encourages regional collaborations among diverse stakeholders through regional science planning efforts. The Chesapeake Bay Program is a watershed-based initiative designed to address ecosystem goals for the Chesapeake Bay and is supported by collaborations among local, state, and federal entities. Organizations oriented around ecosystem-based areas (e.g., Large Marine Ecosystems), such as Regional Fishery Management Councils (RFMCs) and Integrated Ocean Observing System (IOOS) Regional Associations, allow federal and regional interests to be represented and can help further ecosystem-based management. Still others are based on the common needs of groups of states, such as the Gulf of Mexico Alliance, the Northeast Regional Ocean Council, the Great Lakes Regional Collaboration, and the recent West Coast Governor's Agreement on Ocean Health, which represent local and state interests, in current or future collaboration with federal partners.

By promoting regional efforts through the coordination of existing regional efforts or the development of new regional consortia, priorities critical to the stakeholders in those regions can be identified and addressed. To ensure productive regional-federal collaboration, the JSOST, SIMOR, and ICOSRMI will work to ensure effective collaboration between the federal agencies and these regional consortia. Research efforts will be coordinated through a liaison system in which federal agency personnel in each region will interface with regional groups.

With Other Sectors

Several mechanisms currently exist that facilitate interaction and partnerships among multiple sectors. These mechanisms include: formalized interagency activities designed to identify and fund efforts that demonstrate public-private partnerships in specified areas of interest (e.g., National Oceanographic Partnership Program proposal solicitation program, now under the auspices of the JSOST Interagency Working Group on Ocean Partnerships [IWG-OP]) or to pool capabilities, expertise, and information among sectors to address local problems (e.g., Coastal America); stakeholder focus groups and roundtables that bring together parties with vested interest in specific topics or activities (e.g., SIMOR stakeholder focus groups, industry roundtables); and governmental advisory groups (e.g., Ocean Research and Resource Advisory Panel [ORRAP]). Although many of these efforts are initiated at the federal level, they represent forums for discussion and interaction between different groups. The JSOST will actively support and use existing activities under its purview that promote collaborations across sectors and will coordinate with the SIMOR and ICOSRMI to integrate existing federal mechanisms into the COP structure.

With International Groups

By capitalizing on and expanding international efforts, such as international treaties, bilateral agreements, and international scientific forums, the nation can more effectively pursue global research efforts that extend outside its borders, both in terms of influence and impact. Expanding federal interaction with international groups, such as the Intergovernmental Oceanographic Commission, the World Meteorological Organization, the International Maritime Organization, the International Hydrographic Organization, and the Intergovernmental Panel on Climate Change, will also promote effective two-way communication. The JSOST will coordinate with the Oceans Sub-PCC to further engage international ocean governance groups to promote international research efforts in support of the ocean research priorities.

With Resource Managers

Coordination between resource managers and ocean scientists will help ensure that the research needs for effective resource management are met and that the research results are applied by resource managers[37]. The ICOSRMI provides a venue to integrate ocean science and management at the federal level. The SIMOR, sister committee to the JSOST, is currently leading the federal effort to develop mechanisms for such scientist-resource manager coordination. One of these mechanisms is the establishment of task teams consisting of resource managers and researchers dedicated to improving two-way communication between these two communities (e.g., FSSMITT). Communication between resource managers and scientists can also occur as part of nationally sponsored regional outreach efforts (e.g., Sea Grant) and regional councils or groups (e.g., IOOS Regional Associations). Topical or region-oriented activities (e.g., National Dredging Team, coastal-zone conferences) or groups (e.g., RFMCs) can also be used to place new research results into the hands of resource managers, while providing a forum for resource managers to express their research needs and coordinate closely with the research community.

New Mechanisms For Collaboration

Although existing mechanisms for coordination should be used wherever possible, new mechanisms may be required to enable effective partnerships and collaboration. For areas where regional associations are not currently in place, the need for, and development of, a regional mechanism will be examined. Currently, there is no consistent and systematic set of coordinating mechanisms to develop broad-based regional research structures that would provide effective, ongoing regional implementation. The JSOST, working with the SIMOR, will guide a process leading to such a structure.

Additional new mechanisms for other sectors may include industry-university cooperative research centers that promote long-term partnerships among industry, academic institutions, and government, among others. The JSOST IWG-OP, working with its COP partners (e.g., other interagency working groups, JSOST, SIMOR), will identify areas that require new mechanisms for collaboration (e.g., technology development) and develop mechanisms appropriate for those sectors.

Infrastructure Needs

The priorities identified within each societal theme include some discussion of the tools critical to the success of the ocean research priorities. Additionally, elements common to many of the research priorities (e.g., ocean observing and models) are highlighted, along with a series of focused efforts necessary to achieve the full capabilities of these common elements. Central to effectively developing these necessary tools is an assessment of the many infrastructure and technology issues associated with the national ocean research priorities, such as a determination of current federal and national assets, recognizing that no one sector can fulfill all of the infrastructure needs. Development of this assessment will capitalize on the results of existing infrastructure assessments (e.g., fleet renewal plans) and projections of infrastructure enhancement or development (e.g., IOOS, Ocean Observing Initiative [OOI]).

Research Translation

Research translation—transforming research results into readily understandable and usable information, whether for decision-makers, resource managers, educators, or potential workforce participants—requires a common set of skills, currently embodied in many existing organizations. Building on existing mechanisms will be a critical component of moving research results into the broader community for use in education, management, and decision-making processes. Some organizations have begun to work together on topics such as ocean observing and workforce development, and provide a foundation for prototyping broader activities for research translation and expanding such activities.

Decision Support

Translating research results into decision-support and information products will arm resource managers and other decision-makers with the most accurate, research-based information possible. Mechanisms to do this translation already exist in some cases, and can be adapted and expanded. Federal entities, such as the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center, currently assist the nation's coastal-resource management and emergency-management communities by providing access to information, technology, and training, and by producing new tools and approaches that often are applied nationwide. State and local organizations, as well as regional councils and associations, can also serve to provide data, information, and products on marine and estuarine systems deemed necessary by user groups.

Future efforts related to decision support should consider a number of elements, many of which can be modified as needed and applied to education efforts. A good example of elements that should be considered for decision support is outlined in the Strategic Plan for the U.S. CCSP[38]. These elements are:

- Analyses structured around specific questions with consistent communications among all involved scientists and stakeholders addressing the questions
- Early and continuing involvement of, and feedback from, stakeholders, including resource managers, realizing that time and funding to attend workshops is severely limited
- Scientific syntheses and assessments that support informed discussion of ocean issues by decision-makers, stakeholders, the media, and the general public
- Adaptive management for resources and infrastructure
- Information resources that support adaptive management and planning and transfer these resources from research to application
- Methods (scenario evaluations, integrated analyses, alternative analytical approaches) that support policy-making

Research to Operations

Translating research capabilities to operational status is a critical concern for the ocean community, but its associated issues apply to science and industry across the board. Close collaboration with private-sector partners and identification of operational requirements is key to the success of transitioning research. Additionally, successful transitions will build on the tools and mechanisms of partnering (including with other research sectors outside of the ocean community), translation, and workforce development, outlined above.

Ocean Education

A variety of efforts exist to promote and support ocean education. Some entities connect ocean scientists with educators (e.g., Centers for Ocean Sciences Education Excellence). Others excel at introducing ocean-related concepts to the public (e.g., National Estuarine Research Reserve System), while still others focus on community-based outreach. The academic community is responsible for preparing a workforce with the interdisciplinary capabilities and intercommunity knowledge required to address the ocean research priorities. Coordination of education efforts at the local, state, and federal levels is key to establishing an ocean-literate nation.

Understanding how ocean science research and resource management communities can best contribute to improving formal education necessitates working in concert with the Academic Competitiveness Council, a federal group tasked to develop an inventory of federally funded science, technology, engineering, and mathematics (STEM) education programs and evaluate the effectiveness of these programs. The Interagency Working Group on Ocean Education, an entity under the auspices of the JSOST and SIMOR, provides the ideal forum in which to enhance ocean education in conjunction with broader national STEM efforts. These activities will also provide the foundation for a coordinated effort to develop and promote a comprehensive education message about the ocean and its role in the Earth system, and to enable the use of ocean-observing data for management and educational purposes. Such an effort would also help ensure that education-related translation efforts are more effective, that existing ocean science education networks and their ties to regional collaborations are strengthened, and that these individual activities are coordinated.

Developing the intellectual capital to pursue the research priorities requires an assessment of the current technological and scientific (natural and social sciences) workforce to understand gaps, surpluses, and critical skills. This baseline assessment will help identify areas that need to be developed or enhanced to provide the necessary workforce, and provide guidance to universities and other educational institutions about how best to prepare students for current and future workforce demands. Efforts to develop and expand the ocean science workforce include expanding opportunities for obtaining graduate degrees and interdisciplinary training, including experience-based ("hands-on") learning opportunities, developing professional certification programs, and creating competitive incentives to develop and establish training programs.

Assessment and Evaluation

Achieving the goals for each ocean research priority and ensuring that technology and infrastructure needs are met requires coordination among many research efforts. Thus, any regular assessment and evaluation of progress should have a performance-measurement structure that is comprehensive and reflective of multi-agency, multidisciplinary research efforts. The JSOST will consider both a large-scale evaluation of the effort as a whole as well as assessments of individual priority efforts.

Given the multi-agency scope of the ocean research priorities at the federal level, the JSOST intends to establish an umbrella mechanism for federal performance assessment of efforts to address the research priorities. Part of this mechanism will include evaluating the effectiveness of existing mechanisms for interagency and agency-sector (e.g., academia, resource management, nongovernmental organization, private sector) collaborative efforts. The performance-assessment structure in place for the multi-agency, multi-year U.S. CCSP is a useful reference for the development of this umbrella mechanism. The performance assessment will be reported to the ICOSRMI on an annual basis. Results of this assessment will also be used to guide the development of annual implementation activities. The external review that will occur as part of the five-year plan update (see Budget and Plan Update Mechanisms section) will also include an assessment of the effectiveness of the performance-assessment mechanism and an assessment of the success of the implementation.

The foundation of programmatic performance accountability at the federal level for the Ocean Research Priorities Plan and Implementation Strategy will originate from the federal Government Performance and Results Act, which lays out clear guidelines for measuring program success. Milestones and metrics (qualitative and quantitative) that identify targets to be achieved and assess and determine outputs, outcomes, and impacts prior to specific implementation activities will be the centerpiece of an assessment and evaluation system. Performance goals for federal agencies should be consistent with the overarching goals of the individual priority as well as individual agency missions.

Budget and Plan Update Mechanisms

Many aspects of this implementation strategy will be useful for other sectors as they seek to implement the ocean research priorities. This section focuses specifically on federal budgetary aspects and federal actions to update the ocean research priorities.

Budget

Federal efforts to address the ocean research priorities should be considered during the development of the President's budget, as these interagency efforts will greatly increase the effectiveness of federal activities when carried out in a coordinated and integrated fashion.

In consultation with the SIMOR and its partners and upon approval by the ICOSRMI, the JSOST shall produce a memorandum articulating the interagency priorities for the fiscal year (FY) under consideration to inform the annual federal budget process. The memorandum shall reference the specific interagency approaches to address the priorities, the nature of the programs to address each priority, and the partners to participate in efforts to address the priority. Cost estimates and funding options for the federal component of each effort will be determined separately for internal consideration. The memorandum shall be developed and forwarded to relevant federal departments and agencies approximately 22 months before the beginning of the fiscal year (e.g., the guidance memorandum for FY2010 will be released in January of 2008). The JSOST will work to incorporate their key recommendations in the joint Office of Science and Technology Policy (OSTP)-Office of Management and Budget (OMB) annual research and development memorandum. As the JSOST works to incorporate their key recommendations into the OSTP/OMB annual memorandum, the JSOST will also develop and implement a collaborative outreach effort to Congress, states, and stakeholders to advance the national ocean research priorities.

Plan Update

A successful effort to coordinate research nationwide must have adequate flexibility to address emerging challenges and to take advantage of opportunities provided by scientific and technological breakthroughs, while providing the context that comes from development of a long-term perspective.

The federal agencies, through the JSOST, will annually review the national ocean research priorities as part of the ongoing interagency planning and coordination activities undertaken by the COP groups. This annual review of the ocean research priorities will include the near-term implementation steps for the COP groups to address the priorities (both near-term and long-term). Near-term priorities (2–5 years) will be refreshed approximately every five years. On an intermediate frequency (~ 3 years), the JSOST (in cooperation with the SIMOR) will hold "consultation" workshops with major non-federal sponsors, participants, and end users of ocean science and technology development to identify opportunities to enhance the impact of federal research through strategic partnerships. The JSOST will conduct a formal review of the broad, national ocean research priorities every five years in a manner consistent with the development of the current report (e.g., internal assessments, public workshops, public-comment periods, outreach efforts). Such a frequency would allow long-term (decadal) priorities to be revisited and possibly revised. This update will also include a review of the implementation mechanism on the part of the federal government and an assessment of the success of the implementation of the priorities. An external review of the updated priorities and implementation mechanisms for the federal agencies and federal partners will also occur at this time.

Addressing Near-Term Priorities

Initial plans have been developed to address the current set of near-term priorities. Although these plans were developed by the federal agencies, successful implementation relies on the coordinated efforts of a variety of sectors, including state agencies, regional initiatives, academic collaborations, and industry partnerships.

Forecasting the Response of Coastal Ecosystems to Persistent Forcing and Extreme Events

The objective of this near-term priority is to provide managers and decision-makers with the tools needed to prepare for and respond to extreme weather events, natural disasters, and changing natural and human influences. This activity will require the development and integration of predictions of environmental conditions with a full assessment of the vulnerability and resilience of coastal ecosystems and communities.

Approach

This effort will focus on several regional systems and support end-to-end development and integration of observations, research, and forecast models leading to decision-support tools. Research on ecosystem and community conditions, processes, and responses to hazards and forcings, supported by observations, will enhance forecast capabilities and provide the necessary inputs for model development. Enhancement and integration of existing observing capabilities and infrastructure will ensure system interoperability and availability of critical observational data required to support model development, operational forecasts, and decision-support tools. These activities will leverage and advance national efforts to develop and integrate observational and modeling systems while addressing regional needs. This effort will coordinate and integrate existing observational, research, and monitoring programs from several federal agencies, reflecting their mission-focused roles and existing programs. Agency contributions necessary to address this priority include:

- *United States Geological Survey*—Conduct hydrological and biological monitoring and regional geologic and environmental mapping and characterization. Perform research on coastal processes and response to persistent forcing and extreme events. Develop models to forecast hydrologic, landscape, and ecosystem response, and tools to provide assessments of coastal vulnerability and predict future ecosystem conditions.
- *NOAA*—Acquire and integrate (including standards development) monitoring and mapping data from existing and enhanced coastal observation platforms. Conduct assessments to identify region-specific coastal and marine research priorities. Develop community inundation and ecosystem models for assessing storm vulnerability, oil-spill movements, and ecological impacts. Develop a Web-based geospatial framework and digital-elevation models essential for decision-support tools, including socioeconomic and environmental indices.
- *United States Army Corps of Engineers*—Expand shallow-water coastal mapping and wave-observation programs. Develop community, high-resolution coastal models and testbeds to support next-generation models for all agencies, and transition models from research to operational use. Enhance coupling among ecosystem, coastal hydrodynamic, and watershed models to provide integrated management tools for planning, hazard identification, and response.
- *Environmental Protection Agency (EPA)*—Integrate and assimilate observations from coastal-condition surveys and observational platforms. Enhance coastal-condition surveys and assessments. Develop ecosystem models to forecast changes in ecosystem services. Develop models and decision-support tools, including socioeconomic measures of goods and services, to assess changes in ecosystem services resulting from regulatory programs, land-use planning, and natural events.
- *National Science Foundation (NSF)*—Generate real-time, reconfigurable, open-ocean observations that may be used to properly initialize forecast models through the OOI. Conduct research on physical and ecological processes relevant to model development and basic understanding of ecosystem response.

Collaborative Efforts

Region-specific priorities and implementation strategies to address those priorities will result from engagement across a variety of sectors. Federal, state, and academic research and user communities will join in planning and implementation; agencies will cooperatively execute the resulting suite of priority projects.

Comparative Analysis of Marine Ecosystem Organization

The objective of this near-term priority is to improve the management and sustainability of marine ecosystems by better quantifying ecosystem dynamics in relation to human activities. This improved quantification will be used in evaluating the effectiveness of MPAs in achieving management objectives. MPAs incorporate an array of managed marine ecosystems with differing levels of protection, from areas that allow multiple uses to those that restrict take and/or access. A better scientific understanding of the function and impacts of MPAs will assist in making decisions regarding alteration of current MPAs and potential designation of new U.S. MPAs.

Approach

Three primary research activities will address this near-term priority. First, new modeling and analysis procedures will be developed to provide the foundation for comparative analyses and evaluation. This development will also address a key challenge in providing reliable forecasts of biological phenomena supporting ecosystem-based management: the paucity of information on mechanisms controlling complex behaviors within ecosystems. Second, using these quantitative methods, data collected by agencies and academic scientists will be consistently applied to selected ecosystem types in order to provide improved understanding of ecosystem response to environmental change. Third, fieldwork, analysis, and modeling are needed inside and in adjacent areas outside selected MPAs to understand their impacts and evaluate their success on several scales. Agency contributions necessary to address this priority include:

- *NSF*—Improve ways of incorporating uncertainty in model-parameter estimates, the role of size and age structure in population demographics, and spatial dynamics. Facilitate application of quantitative frameworks to data sets to synthesize dynamics across ecosystems and conduct investigations with theory, design, observations, and experiments to interpret the ecosystem and socioeconomic impacts of MPAs.
- *NOAA*—Develop quantitative ecosystem models in partnership with academic and agency partners, apply appropriate data from multiple in-house monitoring databases, and interpret results. Analyze the MPA role in relation to conventional fisheries management tools, in addition to other ecosystem variables.
- *National Aeronautics and Space Administration (NASA)*—Expand existing biological and biogeochemical models to encompass the function of ecosystems under study, and facilitate incorporation of satellite ocean biological and biogeochemical data into models to improve spatial ecosystem-function analyses. Examine quantified variations in key ocean properties from satellite data that may influence the amount and composition of primary productivity in and around MPAs.

- *Department of Interior (DOI)*—Contribute quantitative approaches for species assessments and ecosystem evaluation, coral reef, deep benthic and wetland/estuarine ecosystem data for the models, and relevant seafloor mapping data and analyses, especially where specific human activities that impact ecosystems are affected by the imposition of MPAs.

Collaborative Efforts

The federal agencies and their partners will select a set of geographical regions and MPAs that represent an optimal mix of system types to study. Physical and biological data sets collected by participating scientists and agencies will be used in models developed by the program. This effort will build upon existing academic programs such as Global Ocean Ecosystem Dynamics and the Long-Term Ecological Research network. Partnerships with these and other groups, such as the U.S. Coral Reef Task Force, RFMCs, and state and federal coastal management agencies, will be used to achieve priority objectives and ensure that the research results are used in current management and future area designations.

Sensors for Marine Ecosystems

The objective of this near-term research priority is to improve understanding of ocean ecology on multiple spatial (from individual cells to the global ocean) and temporal (from seconds to decades) scales by improving sensor capabilities and their associated time-series measurements of ocean biological (e.g., genomic), biogeochemical, chemical, and bio-optical properties. Synthesizing multi-scale oceanographic observations with existing data will provide a new way of "seeing" and analyzing ocean-ecosystem functions. This new view will allow researchers to better understand ecosystem response to environmental and climate variability and change, resulting in improved ecosystem-management strategies and protection of public health.

Approach

Three major ecological spatial scales (from cells to ocean regions to the global ocean) need to be observed in a single snapshot, and the information integrated over multiple time scales, to attain the next level of understanding of ocean-ecosystem function. Immediate improvements can be made to *in situ* instrumentation in eco-genomics and interdisciplinary ocean observing, and in optical and bio-optical sensors in support of existing satel-

lite ocean-color data and new space-based biological and biogeochemical observations. Such advancements will provide information at temporal and spatial scales not presently available through any one agency's observing capabilities. Agency contributions to address this priority include:

- *NSF*—Develop *in situ* ocean sensing systems, emphasizing chemical sensors for high-priority compounds such as nutrients, biological sensors for real-time ecosystem analysis, and physical sensors that enable better understanding of transport and fluid velocity. Develop associated technologies such as cyberinfrastructure tools (to link sensors in a broad network context) and advanced power-generation capabilities.
- *NASA*—Improve existing space-based, open-ocean, remote-sensing capabilities of biological and biogeochemical properties (and future satellite sensor capabilities in optically complex or coastal waters) by assessing accuracies in remote-sensing, optical, and bio-optical sensor calibration and validation data-collection activities. Develop next-generation optical and bio-optical field sensors and satellite data products that test new technological and methodological approaches.
- *NOAA*—Develop genomic libraries to advance understanding of ecosystem processes, as well as species abundance and distribution. Develop *in situ* sensors for rapid detection of pathogens, harmful algae, and toxins, and methods to integrate biosensor data with other ocean observations. Develop genomic and proteomic tools and supporting bioinformatics infrastructure to elucidate effects of multiple environmental stressors on marine organisms. Improve video plankton recorders for recruitment process studies.

Collaborative Efforts

Improving existing *in situ* sensors and developing new sensors requires the participation of engineering and research communities. Research communities will validate the new and improved measurements. Application of the data gained from these advances in sensors will be undertaken through the coordinated efforts of researchers and resource managers. Genomic, *in situ* biological, chemical, and bio-optical field observations, remote sensing, and numerical models will be combined into diagnostic tools for regional to global investigations and linked with the developing coastal and offshore observatory efforts to maximize stakeholder participation, input, and use of the advances. Communities will be engaged through a variety of mechanisms, including planning workshops and peer-reviewed research solicitations.

Assessing Meridional Overturning Circulation Variability: Implications for Rapid Climate Change

The objective of this near-term priority is improved understanding of the mechanisms behind fluctuations of the MOC, which will lead to new capabilities for monitoring and making predictions of MOC changes. These predictive capabilities will help identify the impacts of MOC changes on the ocean, climate, extreme weather events, regional sea-level changes, ecosystems, and carbon budgets.

Approach

Given current limited understanding of the MOC, describing the MOC, its variability, and critical processes, and improving the ability to model these will be an early and ongoing emphasis of the program. Enhanced understanding of the MOC system, including its processes and fluctuations, will be gained through the analysis of existing data sets. This expanded understanding will provide the foundation for the design and implementation of a comprehensive MOC observation and monitoring program. In parallel, new forecasting capabilities will be developed by improving ocean models, coupled models, and ocean analyses for their initialization. Finally, interdisciplinary research and modeling studies will be required to characterize the impacts and feedbacks of changes in the MOC on ecosystems, carbon budgets, and regional climate. Initial federal implementation is derived from the work of three agencies and has many linkages with CCSP. Agency contributions to address this priority include:

- *NASA*—Use current and future ocean measurements from satellites to assess processes responsible for MOC variability and to improve ocean models through advanced ocean-state estimation. Refine ocean-state estimates spanning the past 50 years, incorporating all available *in situ* and remotely sensed observations. Use modeling studies to assess impacts of MOC changes on sea-level changes and high latitudes.
- *NOAA*—Conduct modeling experiments on the origins of MOC variability leading to improved understanding of the relative roles of wind and thermohaline forcing. Test models and theories against climate data sets and implement improved models for MOC-related studies.
- *NSF*—Conduct relevant ocean-process studies in the Atlantic and sub-Arctic Oceans to improve ocean-model parameterizations, and perform MOC analysis and modeling studies. Support historical MOC reconstructions and improved data-assimilation systems; initiate modeling studies of the impacts of MOC changes on North Atlantic storminess, ecosystems, and ocean carbon uptake.

Collaborative Efforts

This activity is founded on the coordinated efforts of university, federal, and international initiatives to understand and forecast this large-scale ocean phenomena and its potential for global impacts. This activity will leverage and support the Administration's CCSP priority in "*Assessing abrupt changes in a warming world.*" It builds on ongoing collaboration with international partners such as the United Kingdom's Rapid Climate Change program and the European Union Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies program, as well as developing South American partnerships targeting observing needs for the southern hemisphere branch of the MOC. It takes advantage of national and international ocean remote-sensing satellites, which are part of GEOSS. Activities will be established to engage end-user communities to assess the impacts of decadal climate variability on their decision-making processes and to identify future product suites that would provide needed information.

Endnotes

[1]The term "ocean," unless explicitly noted in the text, refers to the open ocean, coasts (including bays and estuaries), coastal watersheds, and Great Lakes.

[2]"Ecosystem-based management is an integrated approach to management that considers the entire ecosystem, including humans." Scientific Consensus Statement on Marine Ecosystem-Based Management. March 21, 2005. http://compassonline.org/?=EBM (accessed January 24, 2007)

[3]U.S. Commission on Ocean Policy. 2004. *An Ocean Blueprint for the 21st Century, Final Report.* Washington, DC, p. 378

[4]For example, National Research Council. 2003. *Exploration of the Seas: Voyage into the Unknown*. National Academy Press, Washington, DC.; Brewer, P. and T. Moore, eds. 2001. *Ocean Sciences at the New Millennium*. UCAR/JOSS.

[5]Approximately 3.4 million square miles (http://www.uscg.mil/hq/g-o/g-opl/LMR/LMR.htm) (accessed January 24, 2007)

[6]U.S. Commission on Ocean Policy. 2004. *An Ocean Blueprint for the 21st Century, Final Report*. Washington, DC, p. 275.

[7]*Report to Congress: Comprehensive Inventory of the U.S. Outer Continental Shelf Oil and Natural Gas Resources*. Energy Policy Act of 2005, Section 357, U.S. Department of the Interior, Minerals Management Service, Table 2, page 31, February 2006.

[8] http://www.nrel.gov/docs/fy06osti/39479.pdf (accessed January 24, 2007)

[9]Collett, T.S. 1995. Gas hydrate resources of the United States. In: *National Assessment of United States Oil and Gas Resources*. D.L. Gautier, G.L. Dolton, K.I. Takahashi, and K.L. Varnes eds, available on CD-ROM: U.S. Geological Survey Digital Data Series 30.

[10]Collett, T.S. 1997. Resource potential of marine and permafrost associated gas hydrates, in *Oceanic Gas Hydrate: Guidance for Research and Programmatic Development at the Naval Research Laboratory.* M.D. Max, R.E. Pallenbarg, and B.B. Rath, eds, Proceedings of the workshop on Naval Research Laboratory gas hydrate research program, September 23–24, 1997, Washington, D.C. NRL/MR/6100-97-8124, 51 pp.

[11]http://www.glerl.noaa.gov/pr/ourlakes/ (accessed January 24, 2007)

[12]U.S. Commission on Ocean Policy. 2004. *An Ocean Blueprint for the 21st Century, Final Report.* Washington, DC, p. 35.

[13]http://www.oceanservice.noaa.gov/programs/mb/supp_cstl_population.html l (accessed January 24, 2007)

[14]http://www.ncdc.noaa.gov/oa/reports/tech-report-200501z.pdf (accessed January 24, 2007)

[15]U.S. Commission on Ocean Policy. 2004. *An Ocean Blueprint for the 21st Century, Final Report.* Washington, DC, p. 192.

[16]Arctic Council and International Arctic Science Committee. 2004. *Impacts of a Warming Arctic: Arctic Climate Impact Assessment.* Cambridge University Press. Online available at http://www.acia.uaf.edu/pages/overview.html (accessed January 24, 2007).

[17]Short sea shipping uses inland and coastal waterways to move commercial freight from major domestic ports to its destination. (http://www.marad.dot.gov/Programs/sssbroc.htm) (accessed January 24, 2007)

[18]Research efforts for marine transportation will be coordinated with efforts of the cabinet-level Committee on the Marine Transportation System (http://www.cmts.gov/; accessed January 24, 2007)

[19]http://www.uscg.mil/hq/g-o/g-opl/LMR/LMR.htm (accessed January 24, 2007)

[20]http://www.bts.gov/publications/pocket_guide_to_transportation/2005/excel/table_01.xls (accessed January 24, 2007)

[21]http://www.natice.noaa.gov/icefree/FinalArcticReport.pdf (accessed January 24, 2007)

[22]For example, the Multipurpose Marine Cadastre Initiative (http://www.mms.gov/ld/PDFs/MappingInitiative.pdf) (accessed January 24, 2007).

[23]U.S. Climate Change Science Program and Subcommittee on Global Change Research. 2001. *Strategic Plan for the U.S. Climate Change Science Program.* Washington, DC. Online available at http://www.climatescience.gov/Library/stratplan2003/final/default.htm. (accessed January 24, 2007)

[24]Ecosystem health goals and objectives are management tools that guide an ecosystem-based approach to environmental planning and management. Ecosystem goals are statements that describe the desired state of an ecosystem. Ecosystem objectives are more specific. They describe desired conditions for a given ecosystem accounting ecological characteristics and uses.

[25]Millennium Ecosystem Assessment. http://www.maweb.org//en/About.Overview.aspx (accessed January 24, 2007)

[26]The study of the evolutionary relationships of species

[27]http://seafoodandhealth.org/documents/MicrosoftPowerPointPainter.pdf (accessed January 24, 2007); Scoging, A.C. 1992. Illness associated with seafood. *Canadian Medical Association Journal* 147(9):1,344–1,347.

[28]"Seafood" refers to all consumer seafood products as well as all forms of recreational and subsistence take, such as marine mammal harvest by Native Americans.

[29]Excluding allergic reactions to seafood

[30]Kuiken, T., F.A. Leighton, R.A.M. Fouchier, J.W. LeDuc, J.S. M. Peiris, A. Schudel, K. Stöhr, and A.D.M.E. Osterhaus. 2005. Pathogen surveillance in Animals. *Science* 309:1,680–1,681; Taylor, L.H., S.M. Latham, and M.E.J. Woolhouse. 2001. Risk factors for human disease emergence. *Philosophical Transactions of the Royal Society B:Biological Sciences* 356:983–989.

[31]U.S. Commission on Ocean Policy. 2004. *An Ocean Blueprint for the 21st Century, Final Report*. Washington, DC, pp. 340–342.

[32]Mozaffarian, D., and E.B. Rimm. 2006. Fish intake, contaminants and health. Evaluating the risks and benefits. *Journal of the American Medical Association* 296:1,885–1,899.

[33]http://www.ioc-goos.org/content/view/12/26/ (accessed January 24, 2007)

[34]http://www.aza.org/AboutAZA/CollectiveImpact1 (accessed January 24, 2007)

[35]Persistent forcing includes non-extreme, non-episodic influences, such as prevailing climatologic and oceanographic conditions. Persistent forcings include, for example, variations in nutrient and sediment inputs and ocean chemistry beyond those associated with extreme episodic events such as hurricanes.

[36]The number of managed ecosystems continues to increase. For example, in 2006, the United States has designated the world's largest marine conservation area in the Northwest Hawaiian Islands (http://www.whitehouse.gov/news/releases/2006/06/print/20060615-18.html) and, more recently, the world's largest MPA in the Aleutian Islands (http://www.noaanews.noaa.gov/stories2006/s2673.htm). (accessed January 27, 2007)

[37]Subcommittee on Integrated Management of Ocean Resources. 2006. *Implementing the Work Priorities of the Subcommittee on Integrated Management of Ocean Resources (SIMOR): Work Plan*. p. 10 (http://ocean.ceq.gov/about/docs/SIMOR_WorkPlan_Final.pdf) (accessed February 7, 2007).

[38]U.S. Climate Change Science Program and Subcommittee on Global Change Research. 2001. *Strategic Plan for the U.S. Climate Change Science Program*. Washington, DC. Online available at http://www.climatescience.gov/Library/stratplan2003/final/default.htm. (accessed January 24, 2007)

Acronyms

CCSP....................................Climate Change Science Program
CEQ.....................................Council on Environmental Quality
CO_2.....................................Carbon dioxide
COP.....................................Committee on Ocean Policy
DOI.....................................Department of Interior
EEZ.....................................Exclusive Economic Zone
EPA.....................................Environmental Protection Agency
FSSMITT..............................Federal-State Science and Management Integration Task Team
FY...Fiscal year
GEOSS.................................Global Earth Observing System of Systems
GIS.......................................Geographic Information System
HAB......................................Harmful algal bloom
ICOSRMI..............................Interagency Committee on Ocean Science and Resource Management Integration
IOOS....................................Integrated Ocean Observing System
IWG-OP...............................Interagency Working Group on Ocean Partnerships
JSOST..................................Joint Subcommittee on Ocean Science and Technology
MOC....................................Meridional Overturning Circulation
MPA.....................................Marine Protected Area
NAO.....................................North Atlantic Oscillation
NASA...................................National Aeronautics and Space Administration
NEC.....................................National Economic Council
NOAA..................................National Oceanic and Atmospheric Administration
NOPP...................................National Oceanographic Partnership Program
NSC.....................................National Security Council
NSF......................................National Science Foundation
OAP.....................................Ocean Action Plan
Oceans Sub-PCC...............Ocean Sub-Policy Coordinating Committee
OCS.....................................Outer Continental Shelf
OMB....................................Office of Management and Budget
OOI.....................................Ocean Observatories Initiative
ORRAP.................................Ocean Research and Resource Advisory Panel
OSTP...................................Office of Science and Technology Policy
PDO.....................................Pacific Decadal Oscillation
RFMC..................................Regional Fishery Management Council
SIMOR.................................Subcommittee on Integrated Management of Ocean Resources
STEM...................................Science, technology, engineering and mathematics
USCOP.................................U.S. Commission on Ocean Policy

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